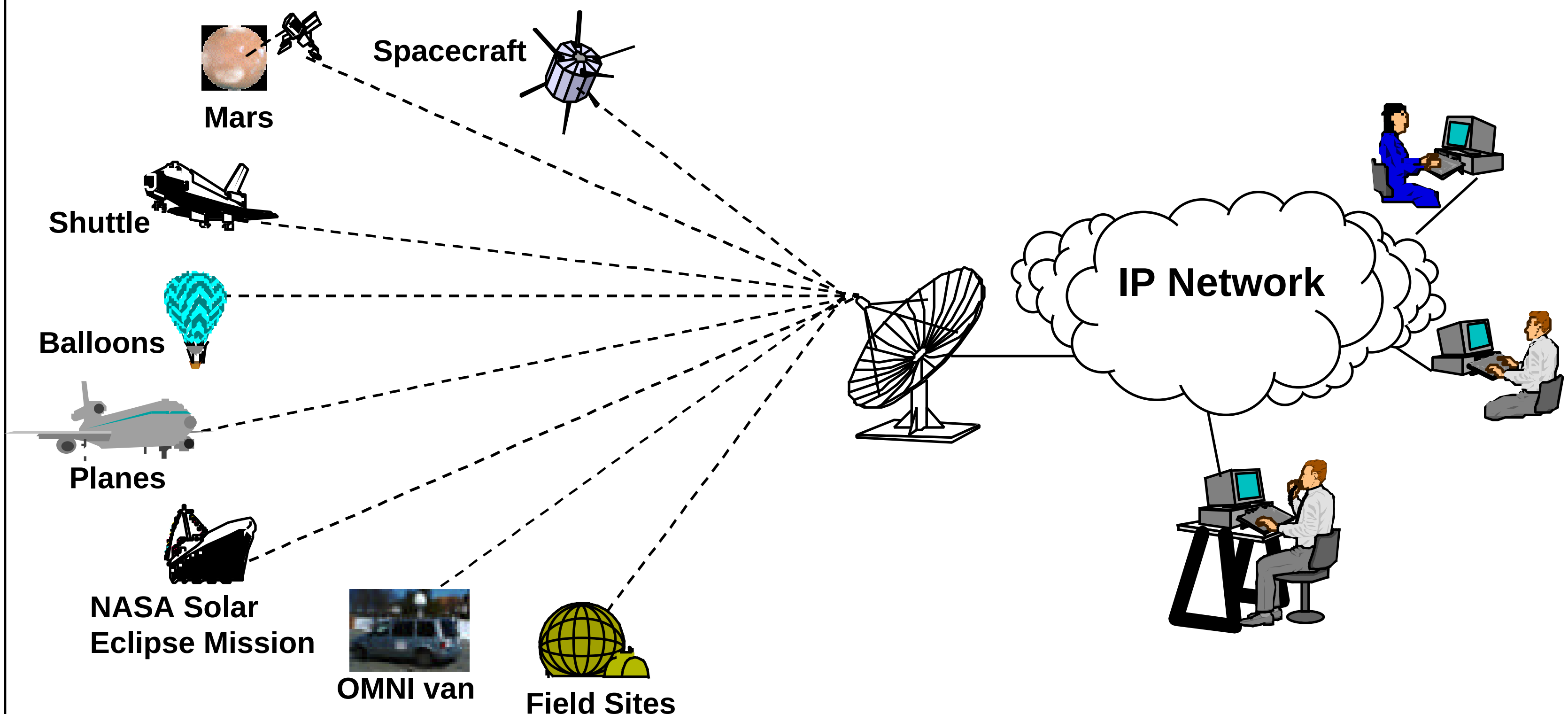
IP in Space Peer Review

Operating Missions as Nodes on the Internet (OMNI)



January 24, 2001

http://ipinspace.gsfc.nasa.gov/

Agenda

1 - OMNI Overview	**(20 min.)**
2 - Technical Details	**(60 min.)**
3 - IP/CCSDS Comparison	**(30 min.)**
4 - Summary	**(15 min.)**
5 - Experimental Results	**(15 min.)**
6 - Future Work	**(30 min.)**
7 - Q&A	**(45 min.)**
-- Lunch --	
8 - Lab Tour -	**(30 min.)**
9 - Final Q&A	

Questions and comments requested during presentation

If the answer isn't clear, please keep asking

1 - OMNI Overview

- What is the OMNI Project
- Communication History
- IP to Space Evolution
- OMNI End-to-end Picture
- Key Issues for Future Missions

OMNI Project

- **Goal - Search for new ways to support future space mission communication requirements with simpler, lower-cost, COTS hardware/software and protocols**
- **Builds on Renaissance activites at GSFC that started in 1995**
  - IMACCS-90 - SAMPEX control center developed in 90 days using COTS products
  - BIOS - Research into full life cycle concepts to take a missions from the design bench, through integration and into operation
  - ISTP reengineering - Built new control centers and level-zero processing system for the SOHO, WIND, POLAR, and GETAIL missions
- **Team members use "lessons learned" designing and implementing NASA's operational space communication systems over the last 25 years:**
  - Command and control systems
  - Level-zero processing systems
  - Communication front-ends
  - Shuttle science instruments
  - TDRSS and shuttle communication systems
  - Developing and operating communication Nascom and OMNI testbeds
- **Participation in standards organizations**
  - GOSIP - OSInet (1989-1991)
  - CCSDS - Panel 3 (1990-1994)

OMNI Personnel

- **NASA/GSFC**
  - Jim Rash - Code 588
  - Dave israel - Code 450
  - Semion Kizhner - 566
  - Gary Meyers - Code 581
  - Johnathan Wilmot -582
  - Freemon Johnson - Code 585
- **Computer Sciences Corp**
  - Keith Hogie
  - Ron Parise
  - Ed Criscuolo
  - Frank Hallahan
  - Thinh Le
- **Collaborations with other organizations**
  - APL, GRC, Cisco, NMSU, Stanford, VyTek Wireless, SSTL,

OMNI End-to-End Approach

- **Identify existing solutions that can meet future space mission communication needs**
- **Changes can be made anywhere from the instrument/spacecraft to the scientist**
- **New solutions not limited to designing new protocols, focus on integration more than new design**
- **Analyze solutions with respect to full mission life cycle from design through development, integration, testing, launch, operations and maintenance**
- **Pick clean, simple solutions based on OMNI team's 100+ years of experience building instruments, control centers, level-zero processing systems and space communication systems**
- **Leverage huge technology resources of the commercial Internet to reduce costs and risk for future missions**

OMNI Concepts

- **End-to-end layered subsystems with clean, tightly specified interfaces similar to the Internet**
  - Encourages multiple vendor solutions and competition
  - Simplifies future upgrades
  - Divides design into smaller subsystems with less need for interface control documents (ICDs)
- **Isolate “space specific” issues (challenged/stressed RF link)**
  - Use existing antennas & RF equipment
  - Simplify front-ends
  - Clean up the link in the RF transmitter/receiver domain
- **Use standard WAN technology and communication equipment over conditioned space link**
- **Address satellite mobility using Internet mobile network solutions**
- **Use UDP where needed as an alternative to TCP**
- **Build on existing NASA infrastructure and Nascom evolution that has built an operational IP backbone out to all ground stations**

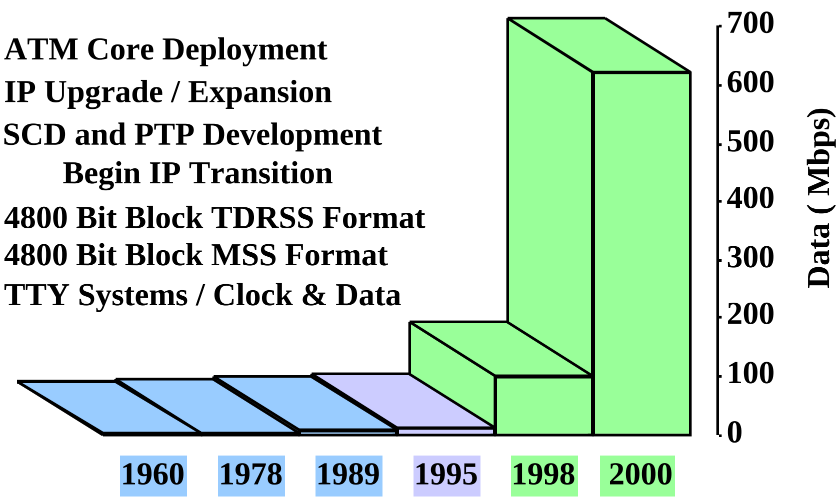
NASA Communication Evolution

- **Communication technology is constantly changing**
- **Major changes occur in communication technology in months**
- **30 years ago NASA needed to design its own communication technology**
- **Now NASA can benefit from using commercial communication technolgy**
- **NASA has upgraded communication systems in the past**
  - Email systems
    - GSFCMAIL
    - ccMail,
    - Internet
  - NASA desktop networks -
    - 3com,
    - DECnet,
    - SNA,
    - IP
  - Nascom -
    - TTY lines,
    - 1200/4800 bit Nascom blocks, MDM,
    - IP Transition, PTP/SCD,
    - ATM backbone

Nascom Upgrades

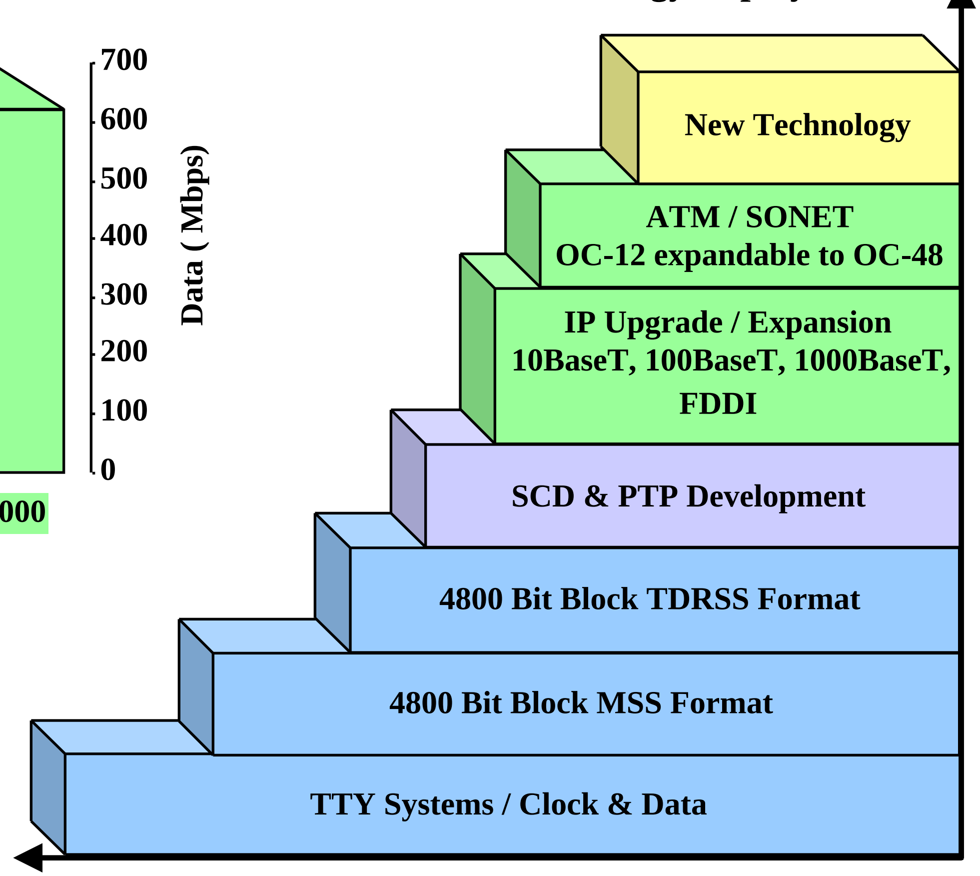
NASA Network Backbone Capacity

(2000) ATM Core Deployment
(1998) IP Upgrade / Expansion
(1995) SCD and PTP Development
Begin IP Transition
(1989) 4800 Bit Block TDRSS Format
(1978) 4800 Bit Block MSS Format
(1960) TTY Systems / Clock & Data



- Future
- Standards Based Systems
- Transition Systems
- Legacy Systems

NASA Technology Deployment



Transitioning legacy 4800 bit block protocol to an IP infrastructure .

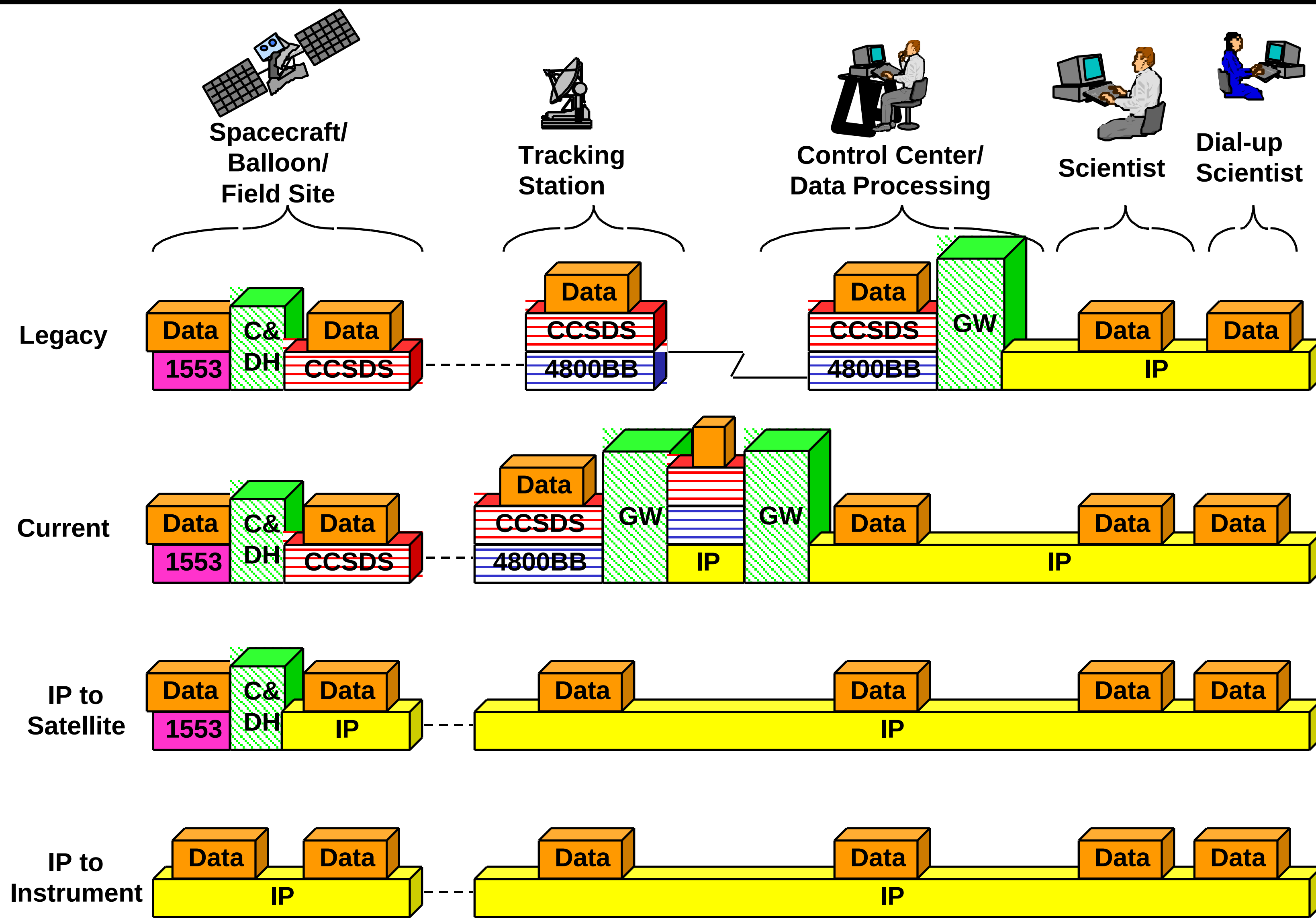
Nascom Success

- **Old systems - staff of 70 programmers to develop and maintain systems**
  - MSS - Message Switch System
  - CSS - Circuit Switch System
  - DCS - Digital matrix switch Control System
  - MDM - Multiplexor DeMultiplexor
  - MACS - MDM Automated Control System
  - DLMS - Data Link Monitor System
  - Statistical Mux
  - Tech Control
- **After IP Transition - staff of 5 programmers**
- **Operations staff also reduced after consolidating systems**
  - Conversion Device Manager
  - IP Network Operation Center
  - Tech Control
- **Upgrading Nascom backbone to higher rates is now much easier using commercial equipment**
- **IP backbone now available for future missions**

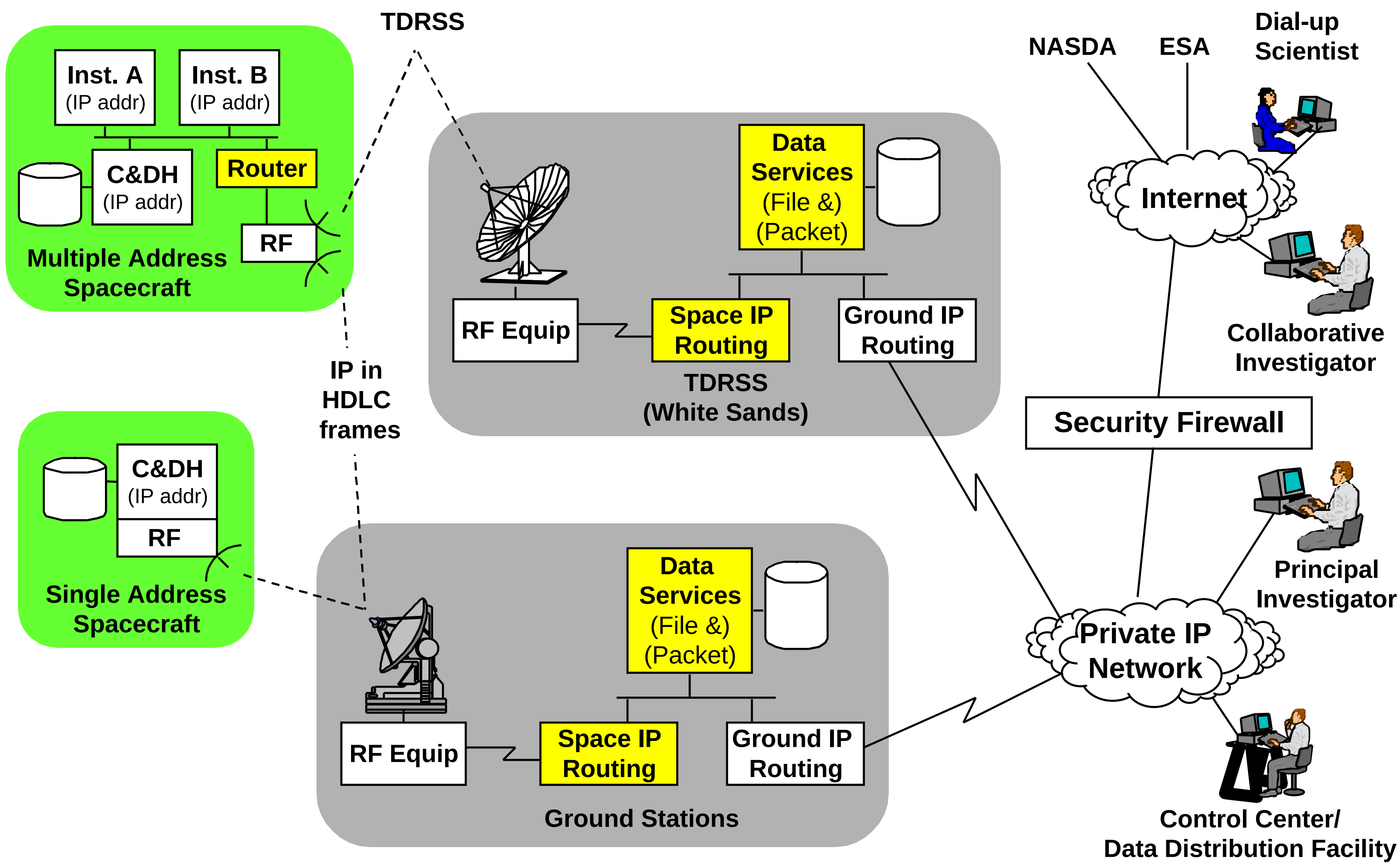
IP to Space Evolution

- **Use COTS standards and HW/SW everywhere, including the space-to-ground link and onboard the spacecraft**
- **Modularity allows swap of individual parts without whole network redesign, just like today's network**
  - Allows physical link changes independent of upper layer equipment (convolutional coding, Reed/Solomon coding, Reed/Meuller Coding, Turbo coding, XYZ coding)
- **Simplify end-to-end architecture to reduce future design, deployment, operations and maintenance**
- **Instruments communicate over standard LAN interfaces during development, integration, and operation**

End-to-End Space Link Evolution

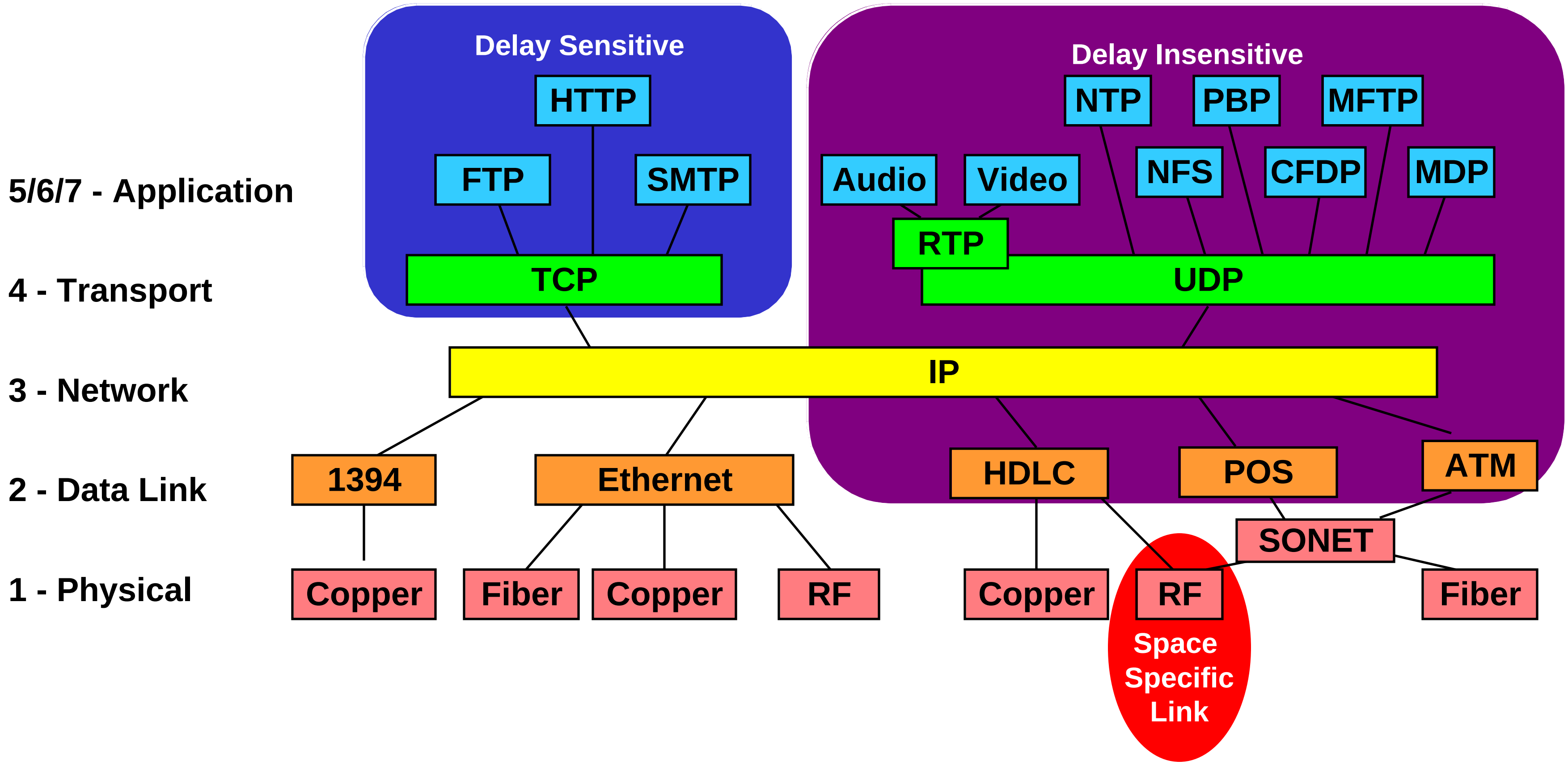


Space Internet Implementation



Layers Are Critical

- **Clean, layered approach is critical:**
  - Isolate special space problems so they can be addressed as needed
  - Allows independent implementations
  - Modularity allows upgrading individual areas



Key Issues for Future NASA Missions

- **Basic communication issues (not protocol related)**
  - Higher data rates, longer distances, RF vs Optical,
- **Mission complexity**
  - More spacecraft, more complex communication topologies
- **Non-technical issues**
  - Less resources, shorter schedules
- **More complex operations concepts require new approaches**
- **Current spacecraft communications are very manpower intensive and highly scheduled - automation is necessary to reduce costs**
- **Use more COTS hardware and software to shorten design/development**

- **The OMNI concept is not really a protocol A vs. protocol B issue - it's about identifying the simplest and most effective way to deliver science data between science systems and users where and when needed**

2 - Protocol Technical Details

- Challenges of Space Communication
- Physical Layer Details
- Data Link Details
- Network Details
- Transport Details
- Application Details

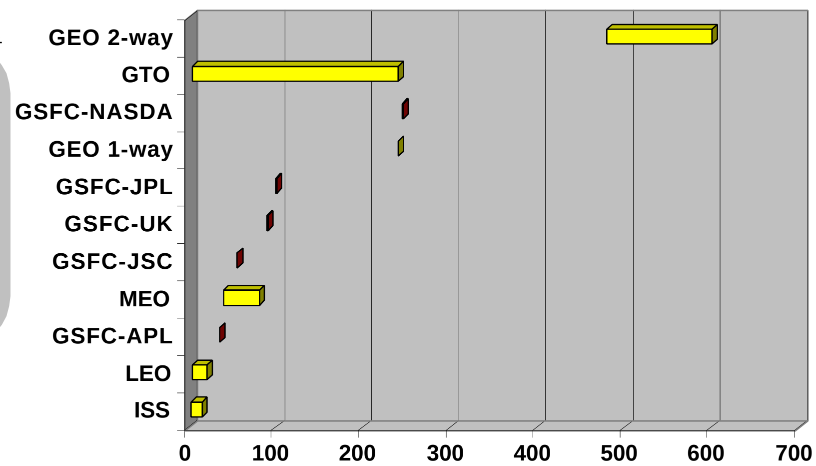
Technical Challenges of Space Communication

- **RF Issues**
  - Constrained power, mass
  - Antenna size, gain, pointed/omni
  - Frequency and bandwidth allocation
  - Physics - Weak signals, 1/r**2, achievable data rates
  - Fade, multipath, interference
  - Error rate
- **Bandwidth/Delay**
  - Asymmetric data rates - adjustable during design
  - Delay - fixed function of the orbit (unless we make signals propagate faster that light)
- **Connectivity/Topology**
  - Possibly unidirectional link
  - Link discontinuity
  - Lack of communication infrastructure in space
- **Identical to CCSDS issues - space is space**

Internet and Space Delay Comparison

- **Many space propagation times are less that on the Internet**

Orbit	Distance (Km)	Light Speed
ISS	400 - 2000	3 - 15 ms
LEO	600 - 3000	4 - 20 ms
MEO	6000 - 12,000	40 - 80 ms
GEO 1-way	36,000	240 ms
GEO 2-way	72,000	480 ms
Lunar	384,000	2.6 sec
L1/L2	1,500,000	10.0 sec
Mars	78M - 376M	9 - 50 min.



Internet	Distance (Km)	Light Speed RTT	Measured Round Trip Time
GSFC-APL	32	.212 ms	35 ms
GSFC-JSC	1600	10.6 ms	55 ms
GSFC-JPL	4000	26.6 ms	100 ms
GSFC-UK	5800	28.6 ms	90 ms
GSFC-NASDA	10,700	71.4 ms	245 ms

Space Link Errors

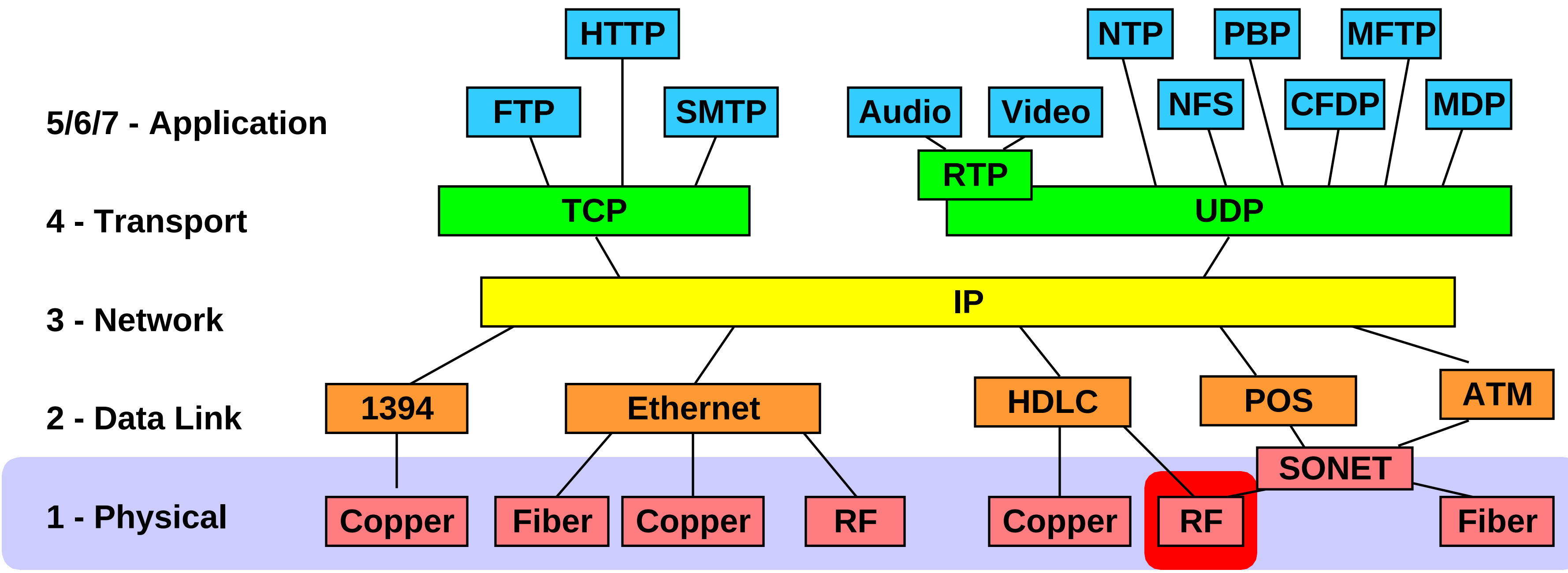
- **Frame loss and approximate BER for WIND and POLAR missions**
  - Data received through DSN stations
  - Outer Reed/Solomon coding
  - Telemetry in 256 byte TDM frames

- **Scientists would not accept data with actual 10^{-5} BER**

File	MB	Blocks	Frames	Drop Lock	Error rate	Drop Lock at 10^{-5} BER
WIND - EI2001009	106	177,791	388,335	16	2.01E-8	7,953
WIND - EI2001013	99	166,134	359,390	16	2.17E-8	7,360
WIND - EI2001014	60	100,009	203,751	10	2.40E-8	4,173
WIND - BI	10	16,550	37,089	2	2.63E-8	760
WIND - BI	6	10,396	23,295	2	4.19E-8	477
WIND -	55	91,070	219,131	9	2.01E-8	4,488
POLAR - BI2001016	29	48,081	107,790	2	9.06E-9	2,208
POLAR - NRT			600,000	20	1.63E-8	12,288
WIND - NRT			218,000	12	2.69E-8	4,465
UARS (TDRSS)			49,671	0	0	508
ERBS (TDRSS)			58,321	1	1.07E-10	933

Physical Layer

- Mechanism for delivering bits across a media (e.g. copper, fiber, RF)
- Trade-off power, antenna gain, distance, noise, data rate, modulation, freq.
- Main issue is making the space RF or possibly Optical link deliver bits
- RF system must be built for space and is independent of upper layer protocols

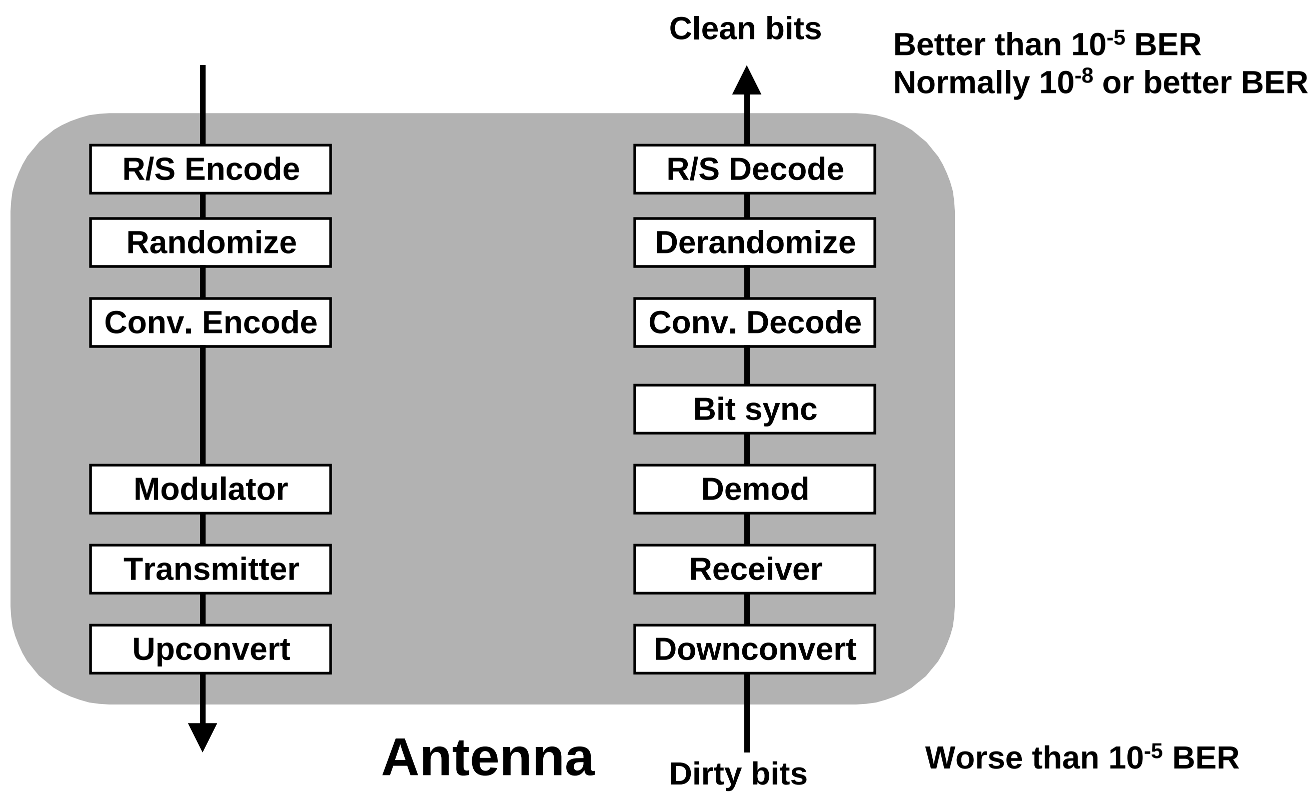


Space Physical Layer Issues

- **Basic challenge is simply delivering bits at needed rate across distance**
  - Antenna size/gain, omnidirectional/pointed
  - Transmitter/receiver frequency, modulation, power, mass,
  - Doppler compensation, interference, fade
  - Forward error coding
- **International agreements on frequency allocation and clearance**
- **Noisy RF links require forward error correction**
  - Convolutional
  - Reed/Solomon
  - Reed/Meuller
  - Turbo codes
- **Constellations**
  - Frequency reuse among nodes
  - Link establishment among constellation nodes
- **Physical layer issues can and should be handled completely independent of upper layer protocols**
- **This is a “space specific” area for CCSDS to address**

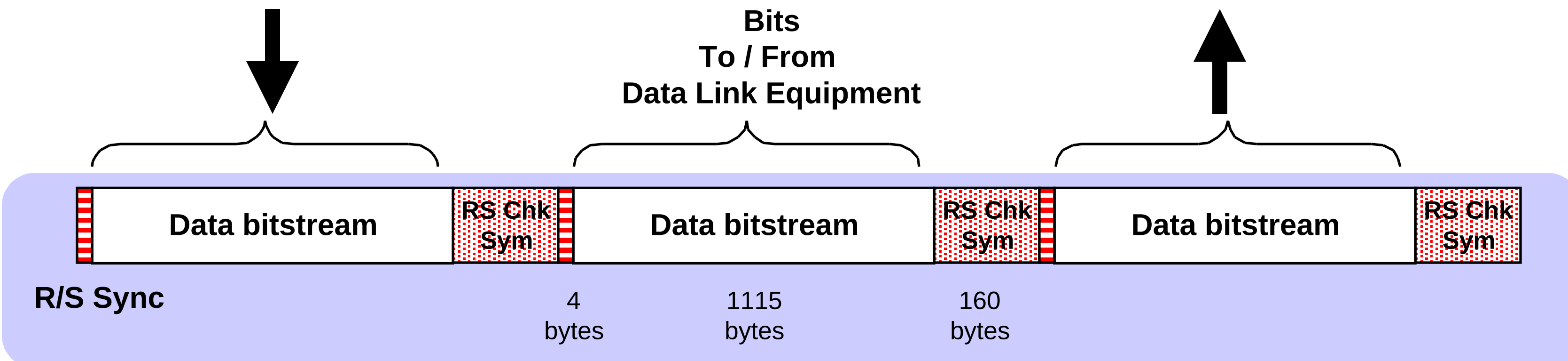
RF Link Bit Level Operations

- All NASA missions (including JPL) design their RF systems to provide 10^{-5} or better BER after physical link coding
- After channel coding, most links operate at 10^{-8} or better
- Scientists would not accept the data recovered with a 10^{-5} BER



RF/Physical View of Data Link

- **Noisy communication links like space need special handling - primarily forward error correction (FEC) to clean up noise/errors in the bitstream**
  - Convolutional coding - bit level FEC
  - Reed/Solomon coding - block level (FEC)
  - Block code FECs use long sync pattern (4 bytes) - helps find unique pattern
  - Fixed length frames - allow “flywheeling” to recover frames with damaged sync pattern



Physical Link Coding

Physical Link

- **RF mod/demod**
- **Up/down convert**
- **Bit sync**

- **Convolutional encode/decode**
- **Randomize/derandomize**
- **Reed-Solomon encode/decode**

Commercial Uses of Reed/Solomon FEC

- **Reed-Solomon coding used to clean up bitstreams everywhere**
  - Storage devices - Compact Disc, DVD, barcodes
  - High-speed modems (ADSL, xDSL, cable modems)
  - Wireless and mobile communications (cell phones, microwave links)
  - Digital television (DVB)
  - Satellite communications (satellite modems)

- **Other options such as convolutional coding are also used alone and in combination with Reed-Solomon**

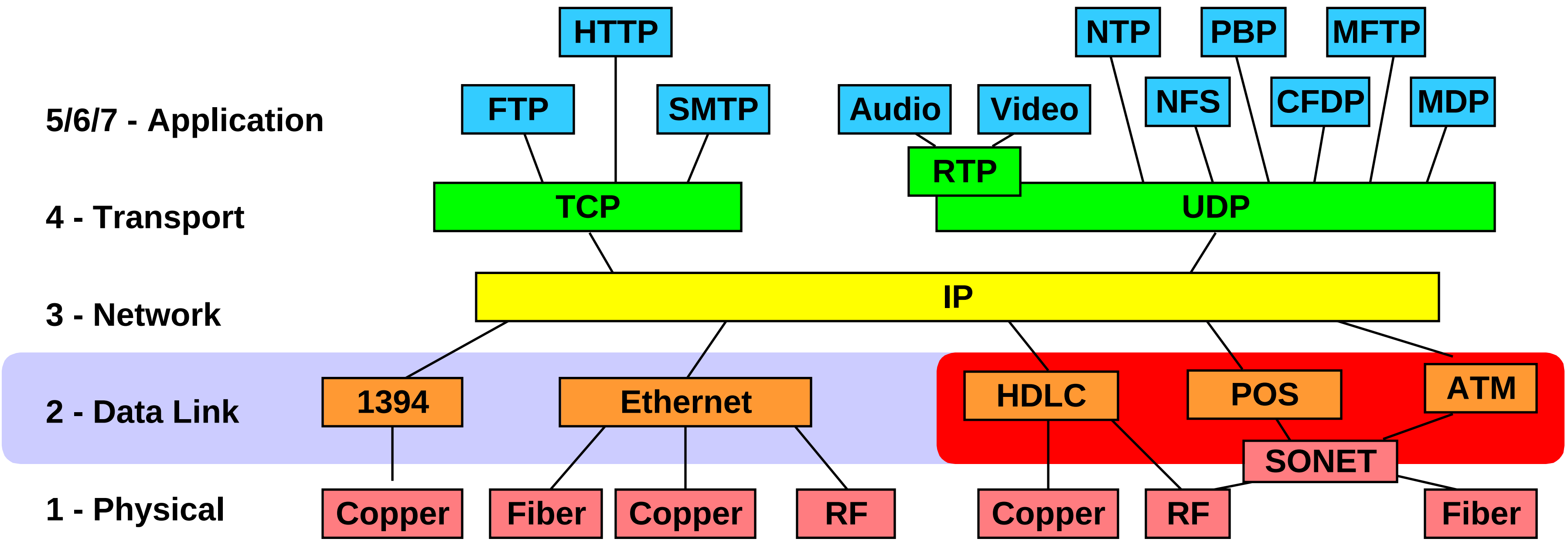
- **In all of these applications the Reed-Solomon coding is independent of the upper layer framing mechanisms**

- **FEC just cleans up the bitstream and operates at a bit-level interface**

- **Different applications use different Reed-Solomon codes selected to meet their specific error characteristics**

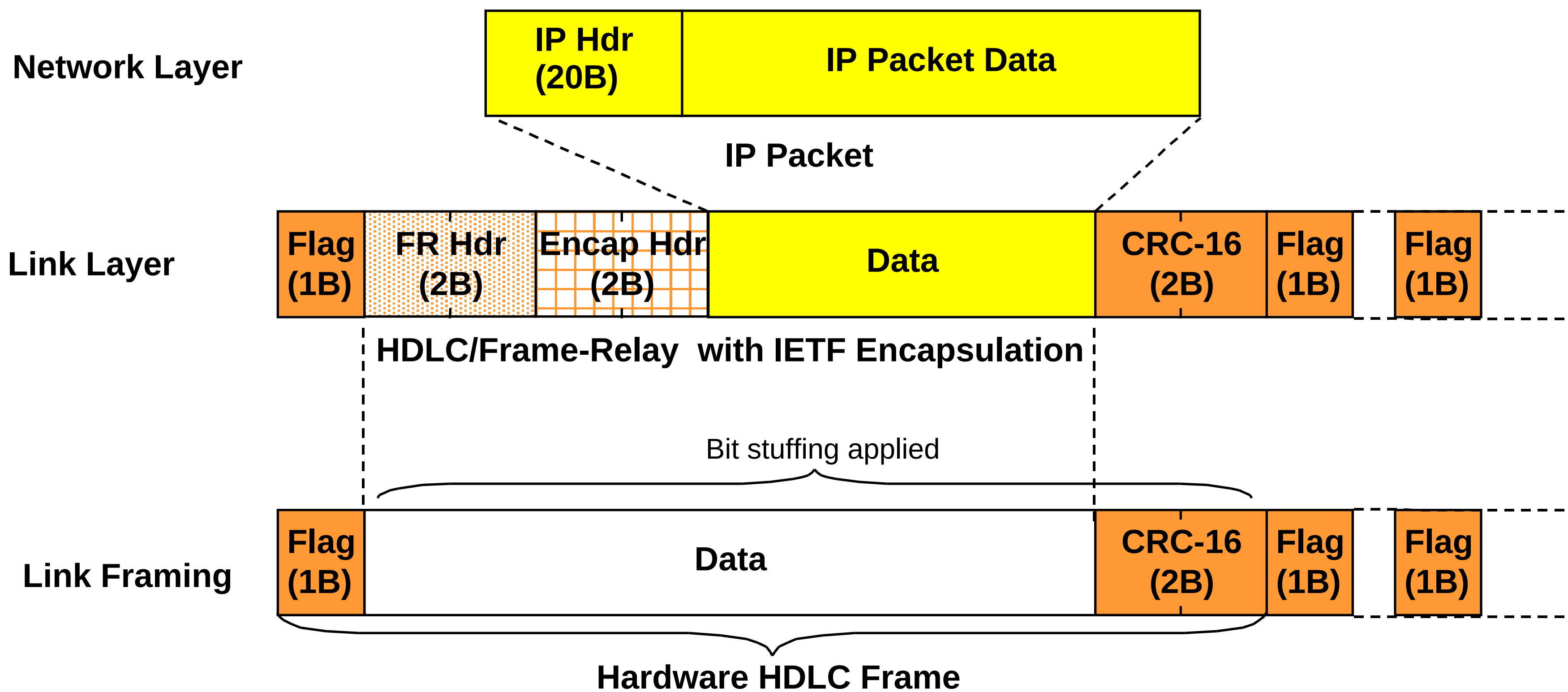
Data link Layer

- Frame upper layer protocol data units over the physical layer
- Add error detection to transmitted frames
- Extract frames from physical layer and pass up
- Perform error detection on received frames



HDLC Space Link Data Framing

- **OMNI using IETF Multi-Protocol over Frame Relay (RFC 2427 over HDLC)**
  - Uses Frame Relay/HDLC - Not X.25 or LAP-B
  - No windowing or flow control - completely independent of delay
- **HDLC FLAG bytes (01111110) between frames - no fill frames or packets**



HDLC Bit Stuffing Overhead

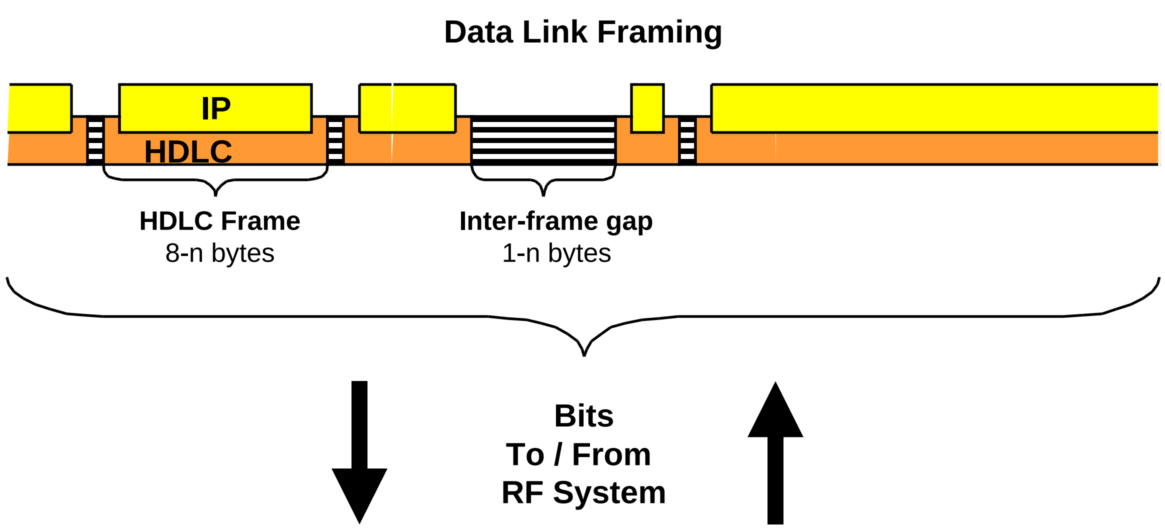
- **Effect of HDLC bit stuffing on sample science data (WIND, POLAR, SOHO)**

File	MB	Total Bits	Stuffed Bits	Overhead
WIND - EI2001009	103	820,163,520	7,321,191	.89 %
WIND - EI2001013	95	759,031,680	7,322,842	.96 %
WIND - EI2001014	54	430,322,112	4,125,045	.96 %
WIND - BI	10	78,331,968	697,327	.89 %
WIND - BI	6	49,199,040	432,996	.88 %
WIND -	58	462,804,672	4,135,223	.89 %
POLAR - BI2001016-72054	30	240,021,120	1,715,776	.71 %
POLAR - BI2001016-72117	31	248,787,072	1,635,811	.66 %
POLAR - BI2001016-72233	20	162,061,056	1,092,277	.67 %
POLAR - BI2001016-72056	153	1,228,237,440	13,663,206	1.11 %
POLAR - BI2001016-72118	172	1,380,528,384	13,502,480	.98 %
SOHO - 01-13T00	254	2,032,283,904	22,445,559	1.10 %
SOHO - 01-13T01	61	490,085,376	3,702,294	.76 %
SOHO - 01-13T02	28	222,693,888	2,182,177	.98 %
SOHO - 01-13T07	258	2,069,539,200	18,621,370	.90 %
SOHO - 01-13T08	66	525,558,528	5,699,767	1.08 %
SOHO - 01-13T09	44	352,356,096	5,699,767	1.03 %
	1,443	11,552,005,056	111,939,731	.97 %

Router View of Space Link

Link Framing

- Locate data frames
- Error check data frames
- Link level addressing
- Send FLAGs between frames (no fill frames or packets needed)

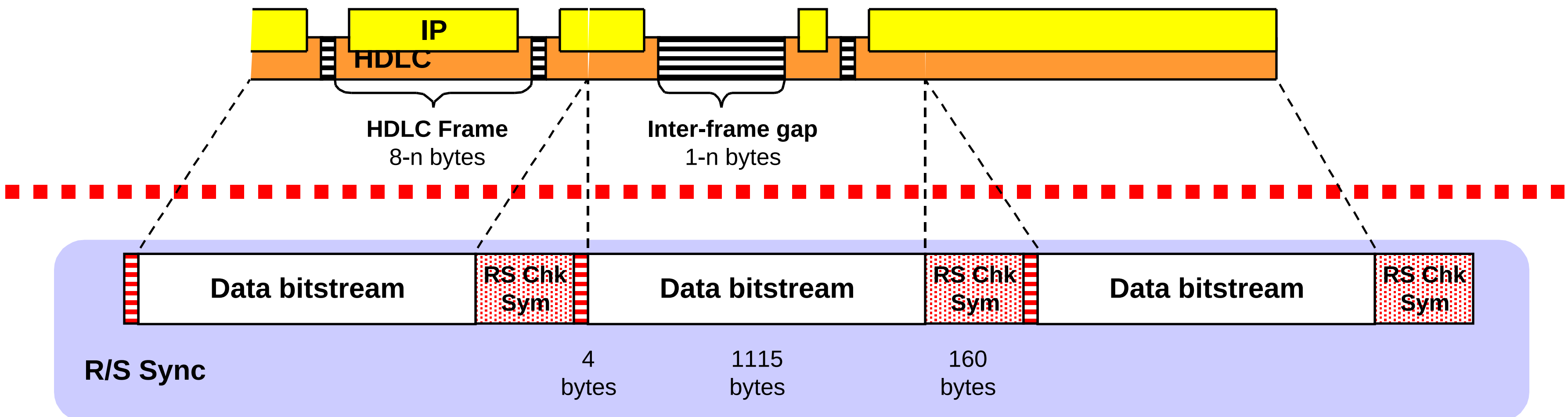


Separation of Coding and Framing

Link Framing

- Locate data frames
- Error check data frames
- Link level addressing

Data Link Framing



Physical Link Coding

Physical Coding

- RF mod/demod
- Up/down convert
- Bit sync

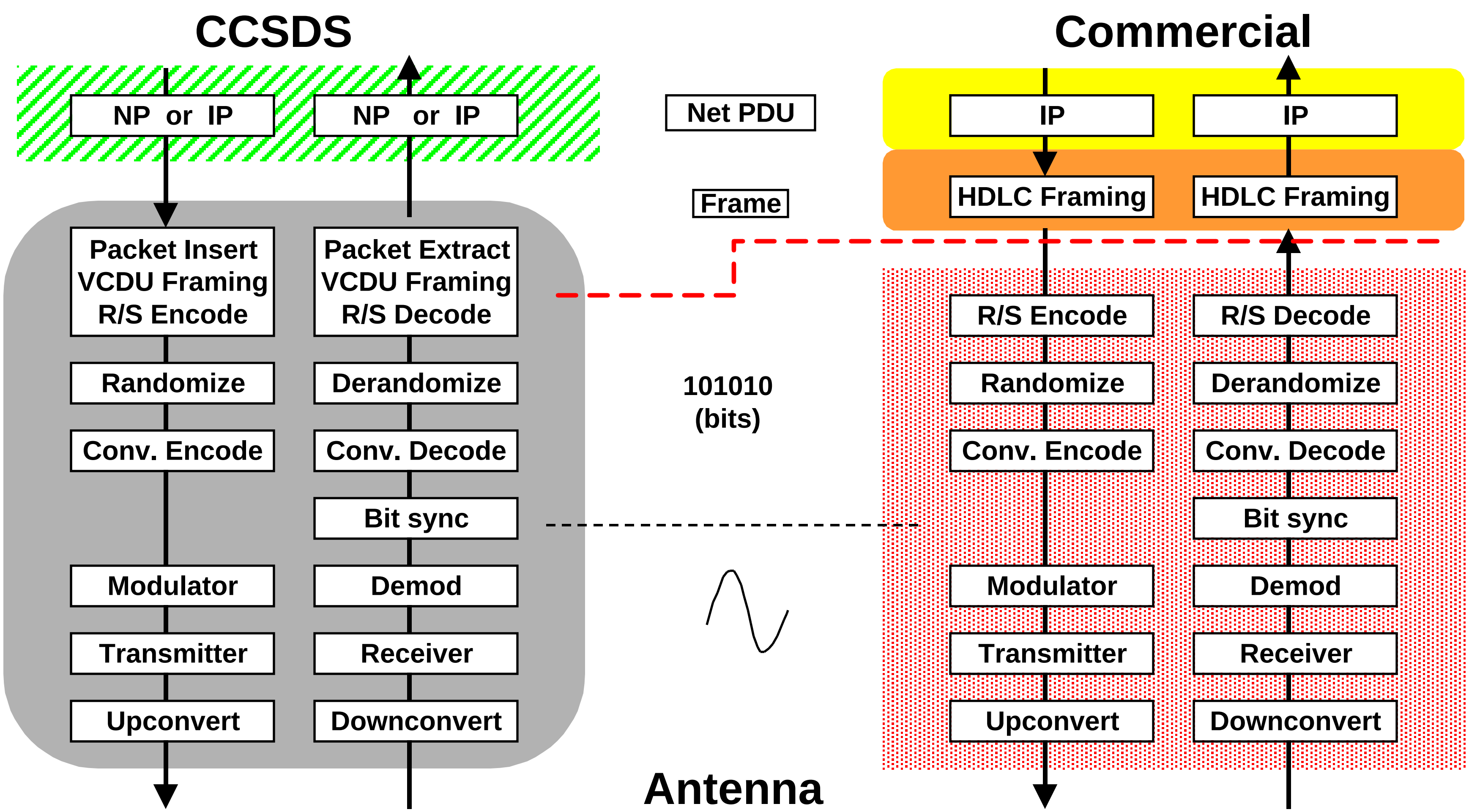
- Convolutional encode/decode
- Randomize/derandomize
- Reed-Solomon encode/decode

Cisco Approach to Space Links

- In 1995 we asked Cisco about implementing Reed/Solomon and CCSDS frame/packet handling in their programmable router interface cards
- Cisco responded indicating that they did not see a viable market there for them
- They also indicated that the standard approach is to use a “satellite modem” to deal with space link specific details
- Satellite modems consist of combinations of Reed/Solomon coding, convolutional coding, randomization, and RF modules
- Satellite modems are widely used to deploy Internet connections across satellite links around the world

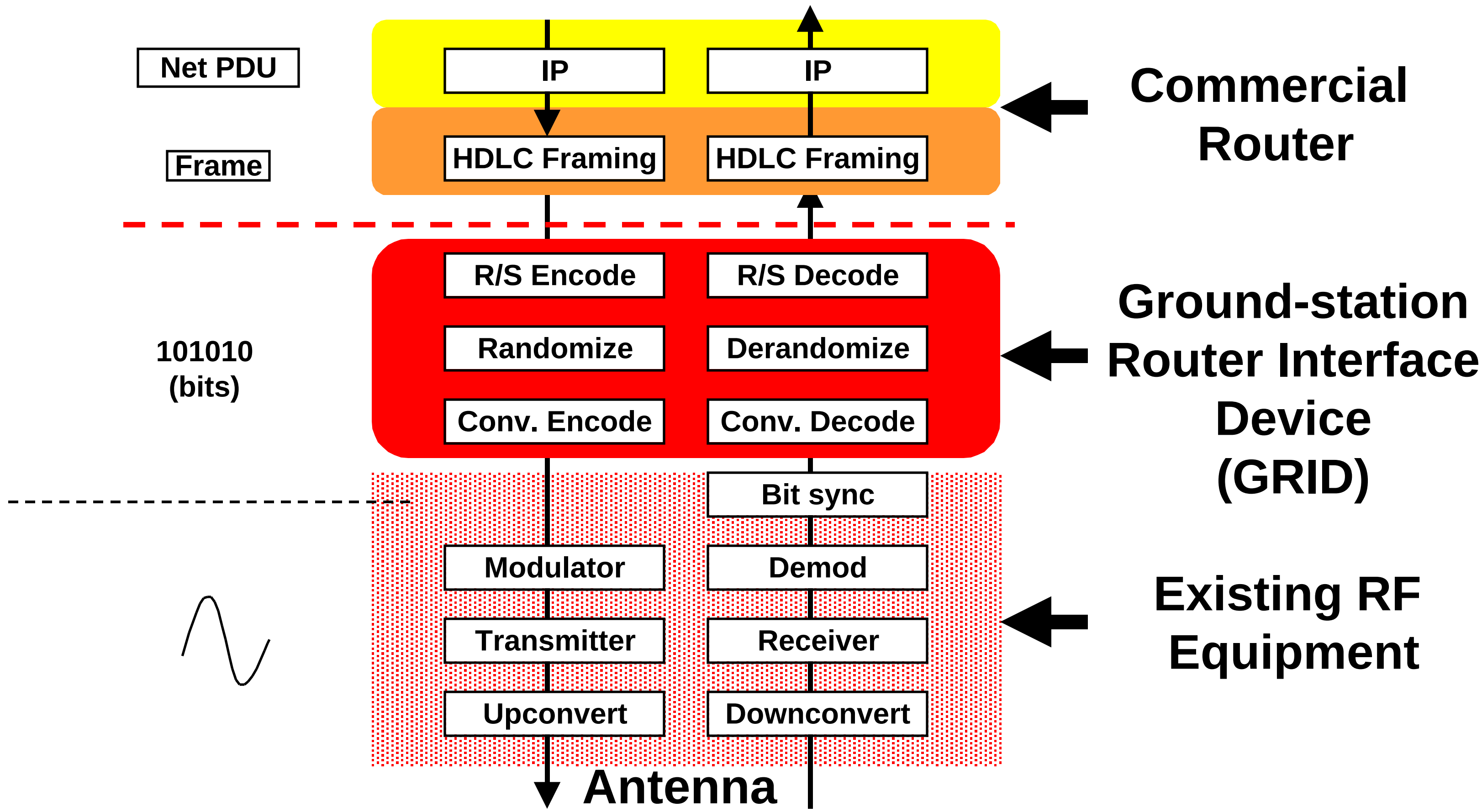
CCSDS vs Commercial Layering

- Very similar except commercial world separates FEC and framing

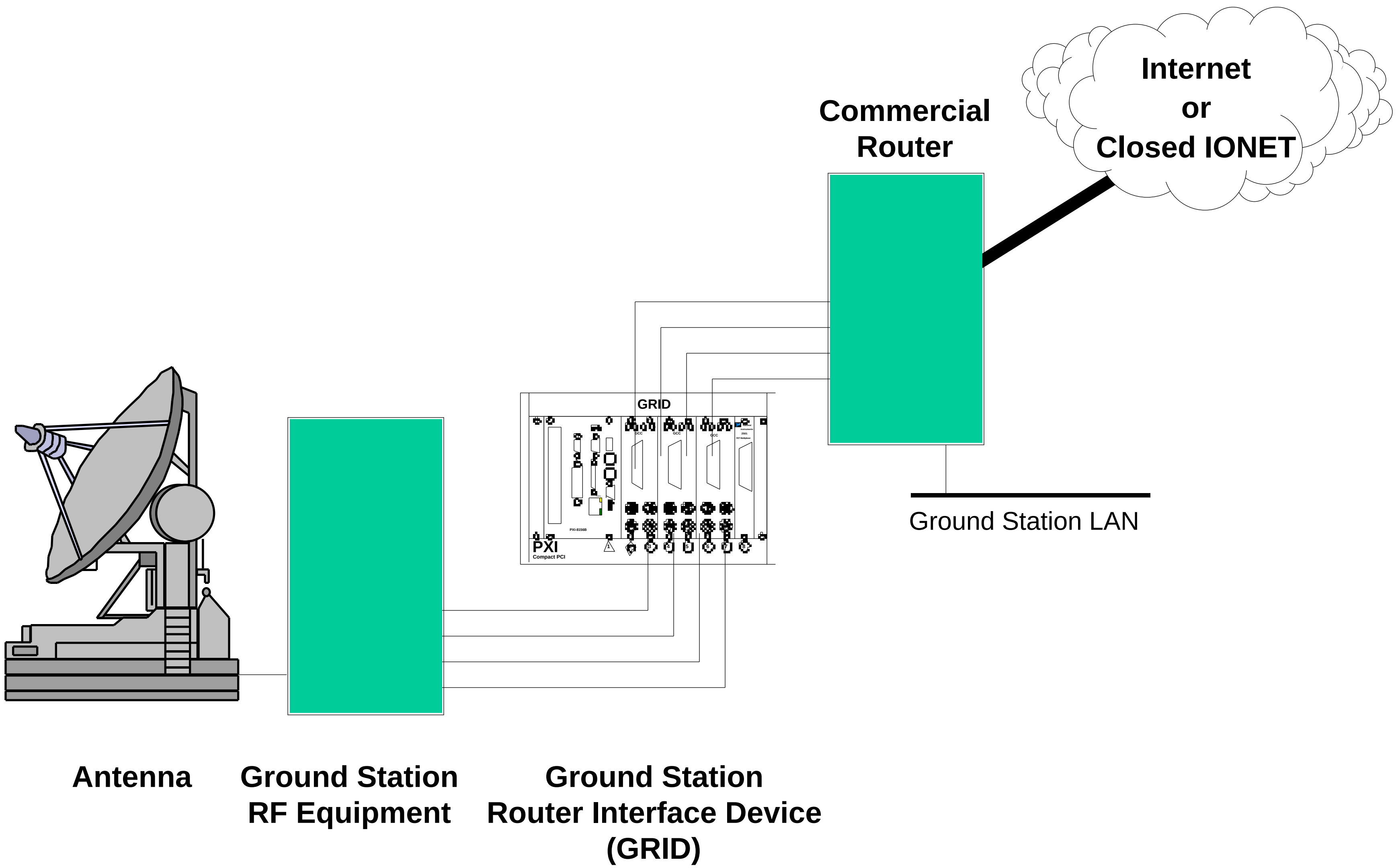


IP Interface for Existing RF Equipment

- A device similar to a commercial satellite modem is needed to connect NASA RF interfaces to commercial routers



GRID Ground Station Installation



GRID Features

- **Provide a cheap and simple interface converter between existing RF equipment at ground station and commercial router interfaces**
- **Only operates on coding and signal levels, no knowledge of data link framing formats**
- **Provide multiple router serial port connections and configurations in a single chassis.**
- **Allow ground stations to connect their command and telemetry data systems to a standard COTS router.**
  - COTS Routers do not provide any channel coding/decoding functions, etc.
  - Most ground stations do not provide standard serial port interfaces to the command and telemetry systems
- **Allow automated configuration from an external computer and provide Data Quality Monitoring status on links.**

GRID Development Status

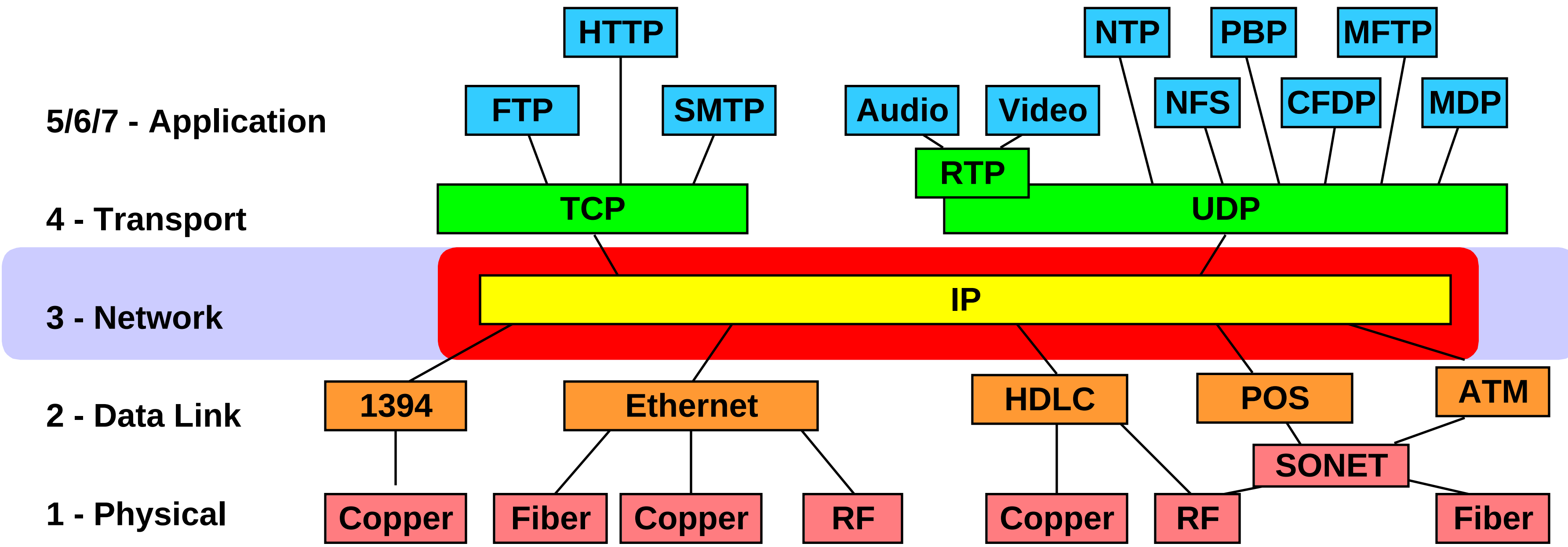
- Currently in design stage
- First prototypes complete by April 2001
- Prototypes will be tested in OMNI FlatSat Testbed and at Ground Stations
- GRID design will become available for Technology Transfer

Onboard LANs

- **Eventually each spacecraft instrument may be on a LAN with its own IP address**
- **Current LAN options being investigated**
  - IEEE-1355
  - IEEE-1394
  - Ethernet
- **Ethernet becoming major industrial LAN technology supporting real-time, deterministic environments**
  - Industrial Ethernet Association - http://www.industrialethernet.com/
  - Industrial Automation Open Networking Alliance - http://www.iaona.com/
  - GE Cisco Industrial Networks - http://www.gecisco.com
- **Lots of hardware and support tools for Ethernet LANs**
- **Building science instruments using common LAN interfaces would greatly simplify integration and test**

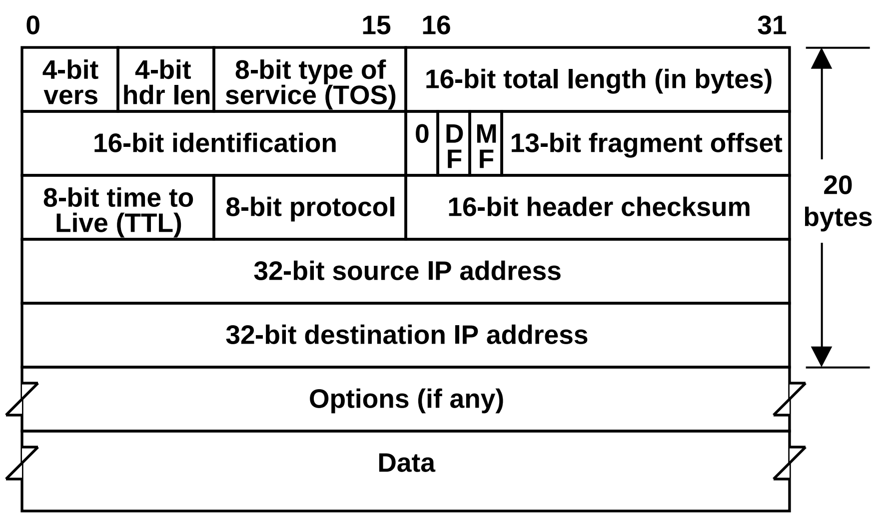
Network Layer

- Provides global, end-to-end addressing for each data packet
- IP packets forwarded by routers
- Automated management of routing tables
- Implemented in routers and end-system operating systems
- Key to the success of the Internet



Network Layer Protocol

- Fixed format protocol header - follow it exactly or you don't communicate
- Standard, fixed format header is the key to global interoperability
- IP hides the details of the data link layers from the upper layer protocols



Network Layer Issues

- **Long delay communication links**
  - IP is completely unaffected by delay
  - IP is simply addresses on the front of your data
  - IP needs no response and works fine to Pluto and beyond
- **Intermittent communication links**
  - IP has no concept of a "session" to be interrupted
  - Each packet contains full address information
- **Data priority**
  - IP has a Type of Service field
  - Routers support priority queuing by transport protocol and port
  - Priority and Quality of Service options are being used and can be enabled on IONET
- **Overhead**
  - Lots of work on header compression due to Voice over IP and streaming video applications (RFC 2507, 2508 - 7 byte headers)
  - High volume data transfers use the largest packets possible

User Data Sizes (bytes)	100	500	1000	1400
IP (20)	16.6%	3.8%	1.9%	1.4%
UDP/IP (28)	21.8%	5.3%	2.7%	1.9%
TCP/IP (40)	28.5%	7.4%	3.8%	2.7%

IP Header Compression

- **The Voice over IP (VoIP) community is very interested in reducing the overhead of IP headers:**
  - IP/UDP/RTP header = 40 bytes (IP-20, UDP-8, RTP-12)
  - Voice samples = 20 bytes (G.729 default)
  - Over 2/3 of VoIP bandwidth would be used for protocol overhead
- **cRTP compresses 40 byte IP/UDP/RTP header to 2-4 bytes**
- **Wireless community also needs header compression (e.g. cell phone email, web browsing)**
- **RFC 2507 - IP Header Compression**

Abstract

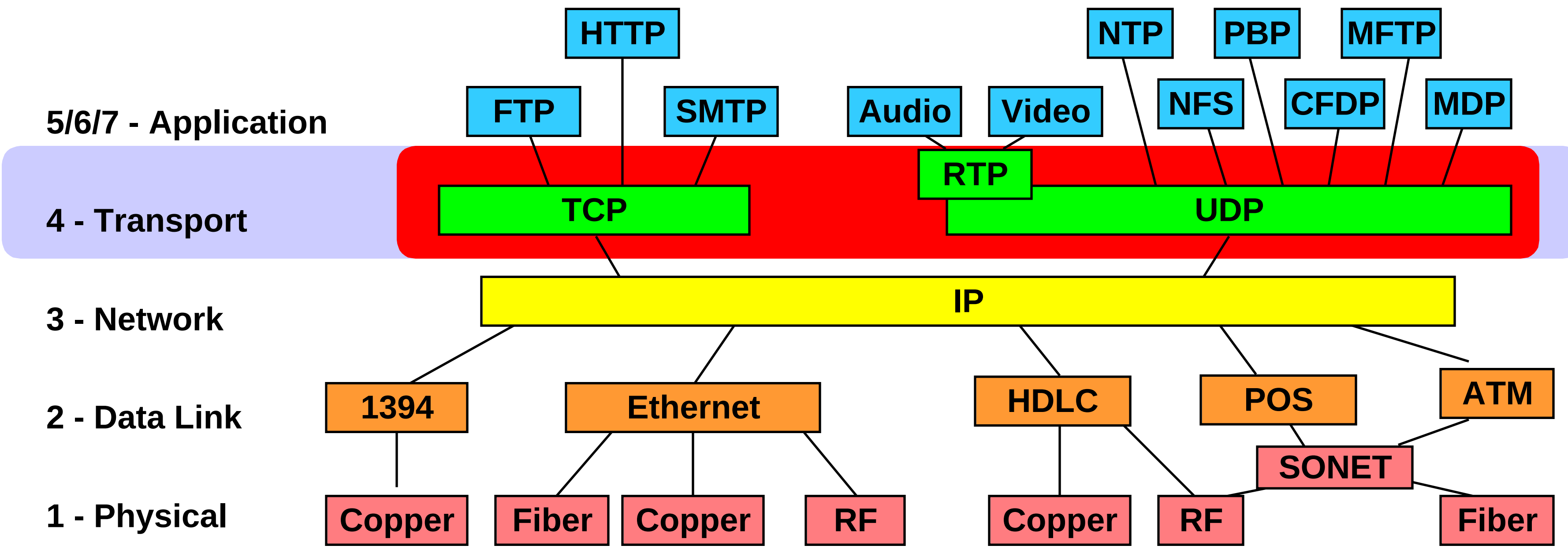
This document describes how to compress multiple IP headers and TCP and UDP headers per hop over point to point links. The methods can be applied to of IPv6 base and extension headers, IPv4 headers, TCP and UDP headers, and encapsulated IPv6 and IPv4 headers.

Headers of typical UDP or TCP packets can be compressed down to 4-7 octets including the 2 octet UDP or TCP checksum. This largely removes the negative impact of large IP headers and allows efficient use of bandwidth on low and medium speed links.

The compression algorithms are specifically designed to work well over links with nontrivial packet-loss rates. Several wireless and modem technologies result in such links.

Transport Layer

- **Common programming interface for applications (sockets)**
- **Primarily two delivery options**
  - TCP - “reliable” end-to-end data delivery
  - UDP - “send-and-forget” data delivery (similar to all current spacecraft frame delivery)
- **Implemented in end-system operating systems, “socket” API**



Transport Layer Protocols

- **User Datagram Protocol (UDP)**
  - Simple header to multiplex user data over IP
  - No session setup or tear-down
  - Works on unidirectional links, unaffected by propagation delay
- **Feedback loop for reliable delivery is implemented by user**
- **Provides Internet interface that operates similar to traditional spacecraft communication systems**
- **Real-time Protocol (RTP) adds support for reconstructing real-time data streams over UDP**

UDP

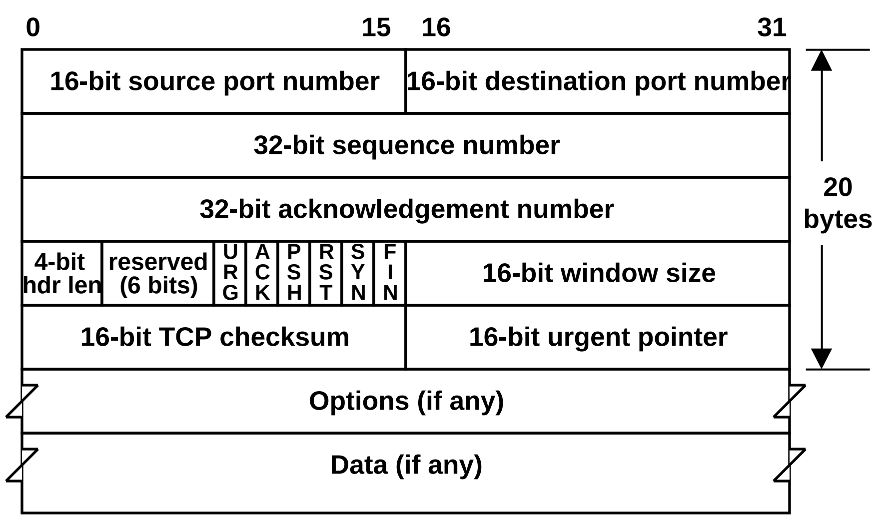
0 … 15	16 … 31	
16-bit source port number	**16-bit destination port number**	**8 bytes**
16-bit UDP length	**16-bit UDP checksum**	
Data (if any)		

RTP

0					… 15	16 … 31	
V=2	**P**	**X**	**X**	**M**	**PT**	**16-bit sequence number**	**12 bytes**
32-bit timestanmp							
32-bit synchronization source (SSRC) identifier							
Data							

Transport Layer Protocols

- **Transmission Control Protocol (TCP)**
  – Same multiplexing features as UDP
  – Additional fields to support “reliable” data delivery
  – Uses sequence numbered datagrams and acknowlegements
  – Also provides flow control in response to network performance
- **Sensitive to combination of data rate (bandwidth) and delay**
- **Sensitive to network errors and congestion**
- **Relatively tight feedback loop between end-systems**

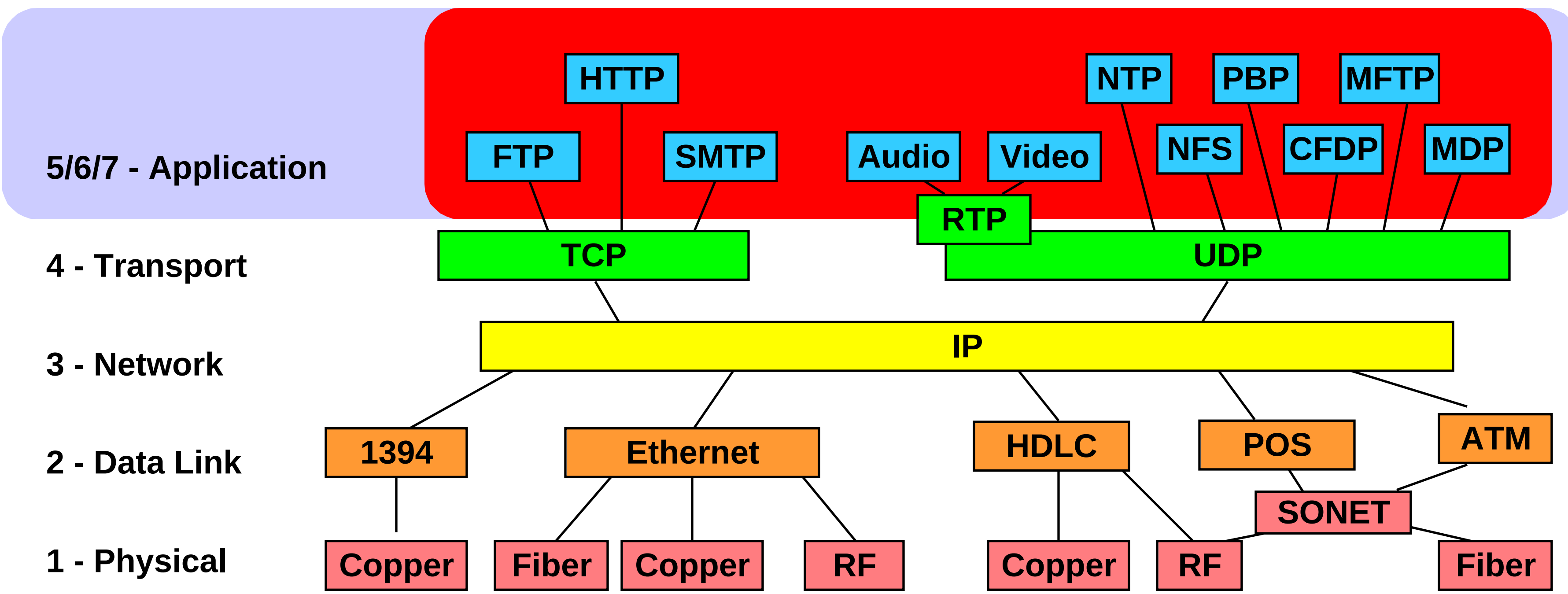


Transport Protocol Selection

- **UDP and TCP exist in the Internet to deal with the wide range of data transfer needs**
- **Space mission designers can pick and choose proper transport protocols for each of their types of data transfer**

Application Layer

- Standard applications for file delivery and other formats (audio, video)
- Applications use the transport protocol best suited to their needs



Application Layer Issues/Protocols

- **Most common application for future spacecraft is “reliable” file transfer**

- **UDP based applications**
  - Network Time Protocol (NTP) - access time server, compute delays, determine time
  - Network File System (NFS) - mount remote file systems, read/write
  - Multicast File Transfer Protocol (MFTP) - commercial file delivery protocol
  - PacSat Broadcast Protocol (PBP) - file transfer protocol for amateur radio spacecraft
  - CCSDS File Delivery Protocol (CFDP) - file delivery with store and forward
  - Multicast Dissemination Protocol (MDP) - file delivery protocol from Naval Res. Lab
  - many others ….

- **TCP based applications**
  - File Transfer Protocol (FTP) - standard Internet file transfer protocol
  - HyperText Transfer Protocol (HTTP) - web file transfer protocol, simpler than FTP
  - Simple Mail Transfer Protocol (SMTP) - file transfer with store and forward
  - many others …..

IP Operations Scenarios

- **Real time telemetry**
  - Unidirectional - UDP
  - Reliable - TCP
- **Reliably Downlink Recorded Science & Engineering Data**
  - Short Delay - FTP
  - Long Delay - MDP / PBP / MFTP / CFDP
  - Store & Forward - SMTP
- **Onboard Clock Synchronization**
  - Synchronization and drift mitigation - NTP
- **Commanding**
  - Store & Forward - SMTP
  - Reliable Realtime - TCP
  - Blind Realtime - UDP

Multicast Dissemination Protocol

- **MDP - developed at NRL, available on Solaris, Linux, Win32**
- **OMNI project getting ready to test this in lab and on UoSAT-12**
- **Basic MDP Protocol Features:**
  - Efficient one-to-many bulk data multicast dissemination
  - Use of selective negative acknowledgement (NACK) receiver-based protocol
  - NACK backoff to avoid receiver message implosion
  - Aggregation of control messaging for bandwidth efficiency
  - Good convergence in high error rate conditions
  - On-demand or timed dissemination of files or directories
  - Optional positive receipts from selected receivers
  - Good properties for asymmetric and tactical operation

Multicast Dissemination Protocol

- **MDPv2 extends this framework by including optional parity-based repair using forward error correction (FEC) coding techniques. Some analyses of the benefits of this hybrid approach is presented here:**
  - “Erasure-based Coding for Reliable Multicast Retransmission”

- **MDPv2 Protocol Extensions:**
  - Parity-based repair mechanism for scalability with uncorrelated receiver loss.
  - Improved repair cycle timing based on automated group round-trip timing
  - Highly scalable implementation (state kept is independent of group size)
  - Support for EMCON (silent clients) modes of file transmission
  - Potential for support of non-real-time and real-time reliable and robust streaming
  - Better properties for asymmetric and tactical operation
  - Tunable protocol parameters for adaptation to extreme network environments

- **Multi-hop store and forward can be added by embedding email addresses in header and using SMTP for final delivery**

IETF Reliable Multicast Framework

- **Reliable Multicast Transport Building Blocks for One-to-Many Bulk-Data Transfer**

RFC2357 lays out the requirements for reliable multicast protocols that are to be considered for standardization by the IETF. They include:

o Congestion Control. The protocol must be safe to deploy in the widespread Internet. Specifically, it must adhere to three mandates:
 a) it must achieve good throughput (i.e. it must not consistently overload links with excess data or repair traffic),
 b) it must achieve good link utilization, and
 c) it must not starve competing flows.

o Scalability. The protocol should be able to work under a variety of conditions that include multiple network topologies, link speeds, and the receiver set size. It is more important to have a good understanding of how and when a protocol breaks than when it works.

o Security. The protocol must be analyzed to show what is necessary to allow it to cope with security and privacy issues. This includes understanding the role of the protocol in data confidentiality and sender authentication, as well as how the protocol will provide defenses against denial of service attacks.

These requirements are primarily directed towards making sure that any standards will be safe for widespread Internet deployment. The advancing maturity of current work on reliable multicast congestion control (RMCC) [HFW99] in the IRTF Reliable Multicast Research Group (RMRG) has been one of the events that has allowed the IETF to charter the RMT working group. RMCC only addresses a subset of the design space for reliable multicast. Fortuitously, the requirements it addresses are also the most pressing application and market requirements.

3 - Internet/CCSDS Comparison

- General comparisons
- Physical/Data link layers
- Network layer
- Transport Layer
- Application layer
- Mission Life Cycle

OMNI & CCSDS Conceptual Differences

- **OMNI and CCSDS agree on many aspects of space communication - however, there are some fundamental and critical differences that have a major impact on overall mission life cycle costs**

- **<u>CCSDS Statements for Discussion</u>**

  "Wired Internet"

  No errors, no delay, continuous connections

  High bandwidth available

  "HDLC won't work in space, very hard to use over block codes (R/S)"

  "SCPS is the same as IP"

  "Using UDP is bad and TCP should be modified for space"

  "Lots of protocol options are good"

  "Congestion is a major problem on mission operational networks"

  "CCSDS protocol hardware and software are COTS

Space Communication Problems/Solutions

Problem	Proto. Layer	Solutions: SCPS/CCSDS	Solutions: COTS (IETF)	Commercial Applications
Transport Propagation delay Asymetric bandwidth Congestion vs loss Protocol overhead	4	**SCPS-TP** Larger windows Fewer ACKs Understands loss Compressed header	**TCP w/extensions** Large windows (RFC 1323) SACK (RFC 2018) Explicit Cong. Not. (RFC 2481) IP header comp. (RFC 2507)	**UDP is always an option** High-bandwidth reliable transfer High-bandwidth reliable transfer Better support for wireless Better Internet efficiency (VoIP)
Network Protocol overhead Mobile nodes Automatic routing Network monitoring Network management	3	**SCPS-NP** Minimal header --- --- --- ---	**IP extensions** IP header comp. (RFC 2507) Mobile IP (RFC 2002) RIP, OSPF (RFC 2328) ICMP (RFC 792) SNMP (RFC 1157)	Better Internet efficiency Mobile Laptops Large scale, automated traffic routing Network traffic monitoring, diagnostics Remote device management/monitoring
Data Link Protocol overhead Multiplexing	2	**CCSDS frame** Minimal header Multiplexing	**IP over** **ATM** QOS High ovhd **HDLC** Min. header **Frame Relay.**	Internet requires wide variety of data links with standard definitions for IP transport over all link formats
Physical Coding (R/S,Viterbi) RF modulation (Freq.)	1	**CCSDS RF & Modulation Recommendations** supported		Fwd. error correction already in use in commercial satellite links. Frequencies specific to NASA

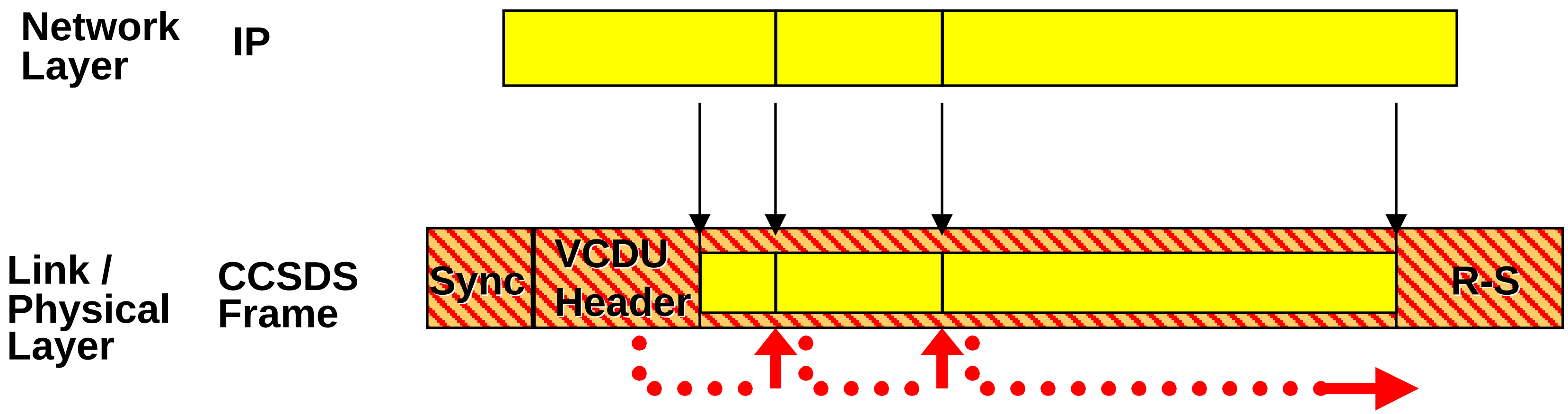
Security Authentication Data privacy	2,3,4	**SCPS-SP** supported supported	**IP Security** Virtual Private Networks IPsec	Security required for banks, secure web shopping, businesses connected via the Internet

Space Communication Problems/Solutions

Problem	Proto. Layer	Solutions		Commercial Applications
		SCPS/CCSDS	COTS (IETF)	
File Transfer Intermittent links	7	**SCPS-FP** Checkpoint/restart	**FTP w/extensions** Resume supported	Dial-up users phone lines drop during long file transfers
File Transfer Intermittent links Very long delay Multiple data paths Store & Forward	7	**CFDP** Application level reliable file transfer	**MDP, MFTP, PBP** Application level reliable file transfer over UDP	Primarily multicast data distribution by large companies distributing data via satellite links Requires loosely coupled feedback loop with minimal ACKs. Exactly what is needed for space

- **Internet is addressing all the protocol issues that were traditionally seen as "Space Unique"**
- **The rapidly growing mobile/wireless market needs solutions**
- **Manufacturers develop solutions quickly because they need them to make more money**
- **RF link (e.g. power, bandwidth, freq., coding) is "Space Unique"**

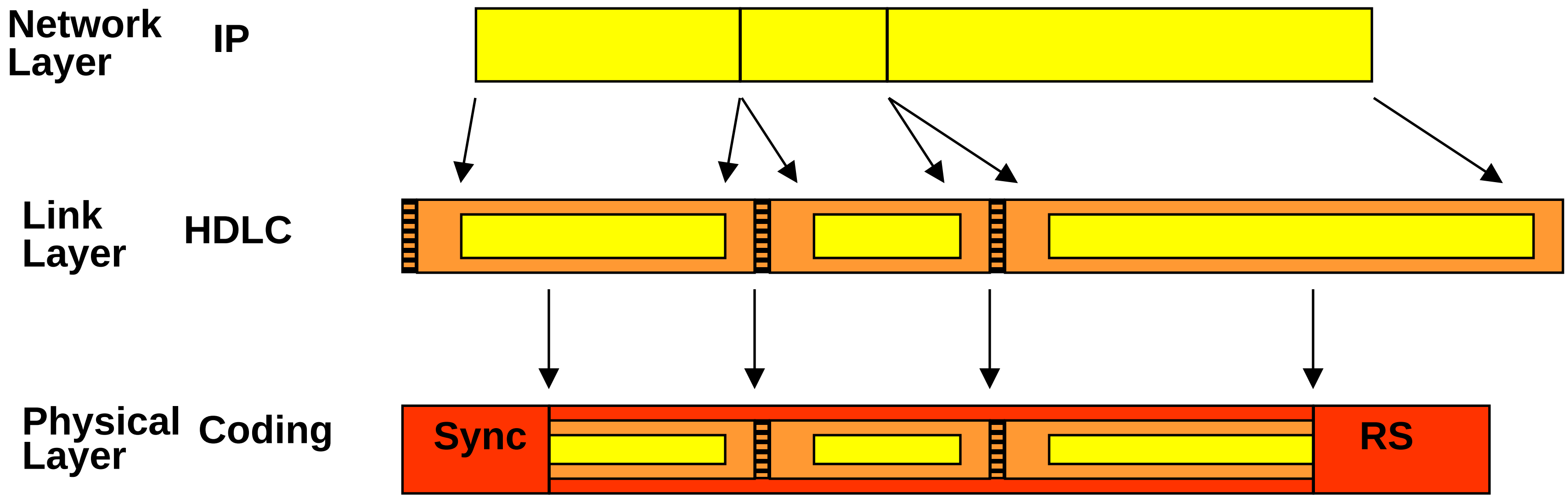
CCSDS Space Link Framing of IP



- IP packets are variable length
- CCSDS frames are fixed length, combining Link Layer framing and Physical Layer coding.
- IP packets become segmented as they are blocked into fixed sized frames.
- Lack of a distinct Link layer with an independent sync mark means that the Link/Physical layer must have knowledge of the internal structure of the network layer in order to extract it.

KEY: Network Link Physical

OMNI Space Link Framing of IP



- IP packets are variable length
- One HDLC frame per IP packet, with independent sync marks
- Coding at the physical layer provides a protected “bit-stream” service for the link layer. Physical layer requires no knowledge of link layer structure.

KEY: Network Link Physical

IP & SCPS-NP Comparison

- IPv4 - fixed 20 byte header
- Options after fixed header
- Automated routing protocols
- Built into all operating systems

- SCPS-NP - variable header 4-20 bytes
- Options throughout header
- Highly managed configuration
- Not available in any operating system
- Reduced overhead drops features

IPv4 header (20 bytes), bits 0 – 15 | 16 – 31

0		15	16			31
4-bit vers	4-bit hdr len	8-bit type of service (TOS)	16-bit total length (in bytes)			
16-bit identification			0	DF	MF	13-bit fragment offset
8-bit time to Live (TTL)		8-bit protocol	16-bit header checksum			
32-bit source IP address						
32-bit destination IP address						
Options (if any)						
Data						

20 bytes

1B Dest.

3-bit VPI	13-bit	4-bit TP-ID	4-bit Control	8-bit Dest addr

1B Dest & Src..

3-bit VPI	13-bit	4-bit TP-ID	4-bit Control	8-bit Control cont.
8-bit Dest addr	8-bit Sourcet addr			

4B Dest.

3-bit VPI	13-bit	4-bit TP-ID	4-bit Control	8-bit Control cont.
8-bit Dest addr				

4B Dest. & Src. & QOS

3-bit VPI	13-bit	4-bit TP-ID	4-bit Control	8-bit Control cont.
32-bit Dest addr				
32-bit Sourcet addr				
8-bit Basic QOS	8-bit Hop count	16-bitchecksum		

IPsec & SCPS-SP Comparison

- IPsec - variable headers
- Lots of options
- Lots of commercial implementations
- Automated support tools
- Used by thousands (e.g. banks, corporations, .coms) for critical applications

- SCPS-SP - variable headers
- Lots of options
- No commercial implementations
- No automated support tools
- No major usage

TCP & SCPS-TP Comparison

- TCP - fixed 20 byte header
- Options after fixed header
- Retransmit and flow control logic
- Built into all operating systems

0 15 16 31

16-bit source port number								16-bit destination port number
32-bit sequence number								
32-bit acknowledgement number								
4-bit hdr len	reserved (6 bits)	URG	ACK	PSH	RST	SYN	FIN	16-bit window size
16-bit TCP checksum								16-bit urgent pointer
Options (if any)								
Data (if any)								

20 bytes

- SCPS-TP - standard TCP header
- SCPS-TP options in TCP option space
- Modified TCP control logic
- Not available in any operating system

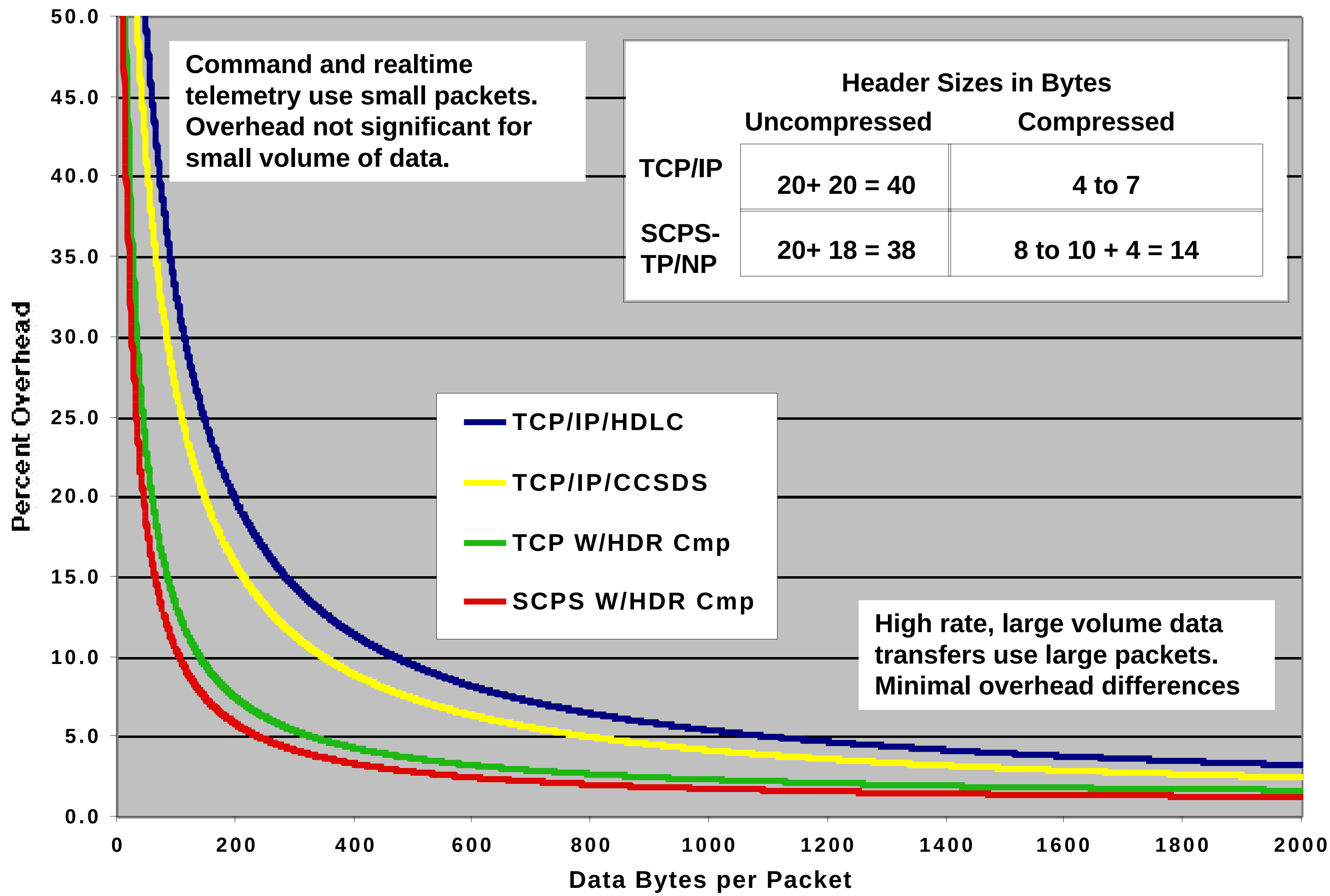
- Best effort mode
  - –If application trusts TCP reliable delivery, errors break application logic
  - –If application handles reliable and unreliable modes, might as well use UDP and avoid all the TCP session setup and teardown

- Compressed SCPS-TP header
  - –Variable lengths
  - –Compression by dropping features

8-bit Connect ID	8-bit Comp. Hdr bit vector	16-bitchecksum

8-bit Connect ID	8-bit Comp. Hdr bit vector	32-bit sequence --->
<----- number		16-bitchecksum

Bit-Efficiency Comparison



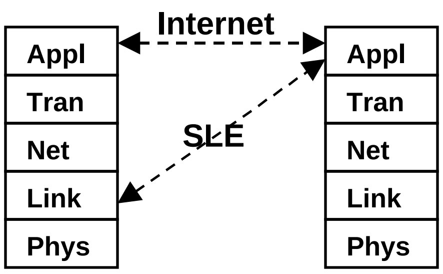
Header Sizes in Bytes

	Uncompressed	Compressed
TCP/IP	20+ 20 = 40	4 to 7
SCPS-TP/NP	20+ 18 = 38	8 to 10 + 4 = 14

Internet & SLE Comparison

- CCSDS Space Link Extension (SLE) concept is difficult to relate to Internet protocols. Based on Internet concepts like CORBA and remote objects.
- Internet layering focuses on delivering data between users and hiding the lower layer framing details.
- Remote access LAN/WAN analyzers can return frames for diagnostic purposes.
- Internet has lots of remote monitoring and management protocols and packages

- SLE contains data delivery and network management functions
- SLE requires gateways between space link and ground network
- SLE concept focuses on delivering space link data frames and packets to users for further processing



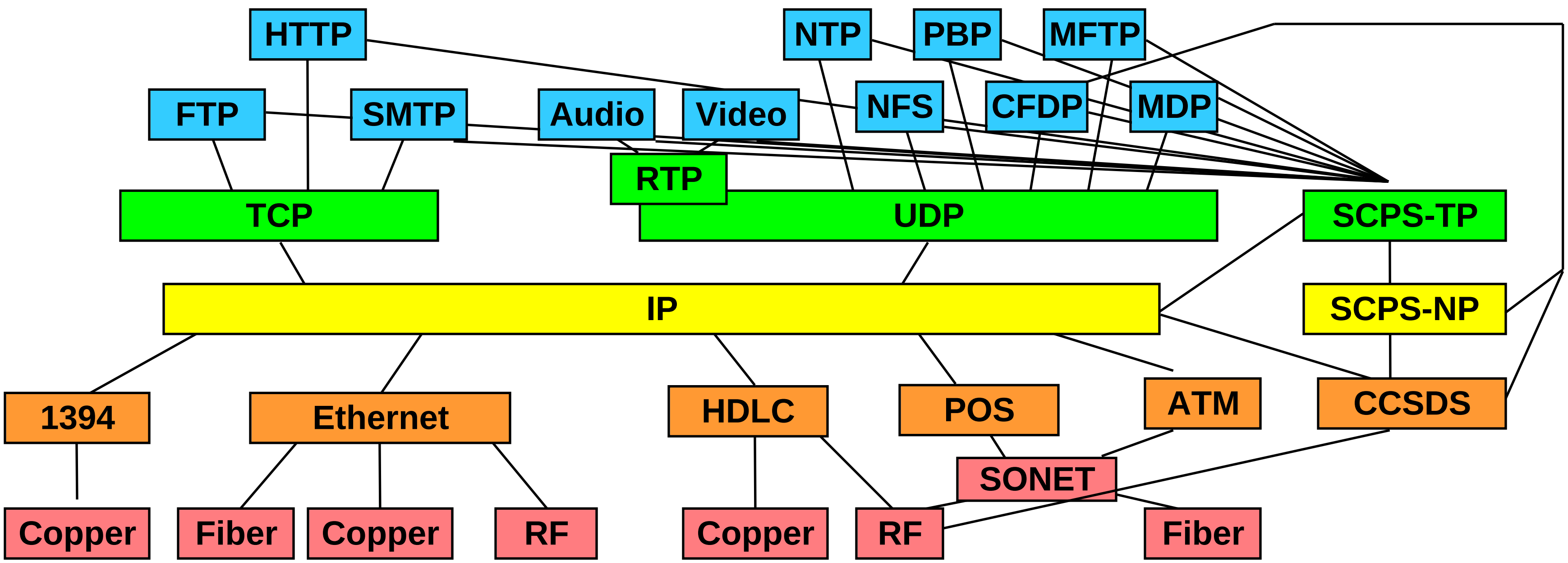
Reliable File Transfer Comparison

- **Internet uses reliable file transfer applications built on both TCP and UDP**
- **TCP**
  - FTP
  - NFS
  - HTTP
- **UDP**
  - NFS
  - MDP
  - MFTP
- **MDP application level store&fwd, add third party easily**
- **These all readily available**

- **CCSDS has reliable file transfer applications built on SCPS-TP and UDP**
- **SCPS-TP**
  - SCPS-FP
  - CFDP
- **UDP or CCSDS packets**
  - CFDP
- **CFDP application level store & fwd through third party**
- **Being developed**
- **Is there anything special CFDP can do that others can't already do?**

Internet + SCPS

- SCPS protocols perform functions similar to standard Internet protocols but provide a more complicated layering options



Internet & CCSDS Comparisons

- **Internet Concepts**
  - Goal is global interoperability among systems and vendors
  - Functionality and interoperability is critical
  - Highly layered with clean, well-defined interfaces between layers
  - Automated operation to support large scale operations
- **CCSDS Concepts**
  - Limited usage in a highly managed network environment
  - Bit efficiency is critical, drop functionality to compress
  - Compressed layers, lots of options
  - Managed gateways required to interface with the Internet

Life Cycle Support Comparison

Life Cycle Area	Functions/Componednts	Internet Approach	CCSDS Approach
Hardware	RF interfaces for spacecraft and ground ends of RF link	Flight - Custom Ground - COTS	Flight - Custom Ground - Custom
Software	Protocol processing support in COTS operating systems	Standard COTS	Custom
Development Tools	Widely supported programming libraries, performance modeling tools	Standard COTS	Custom
Test/Debug	Protocol analyzers with decode, traffic analysis,	Standard COTS	Custom
Monitoring/ Management	Automated routing protocols, network status, network management, traffic analysis	Standard COTS	Custom

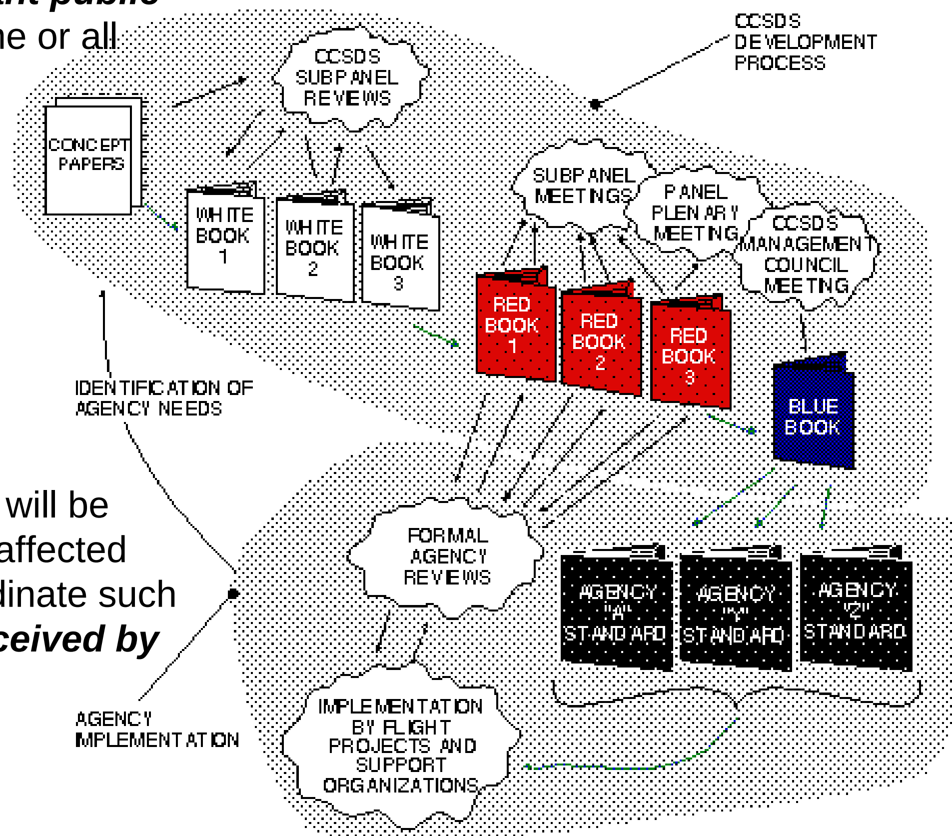
Standardization Issues

- **What is the IETF**
  - International communication/networking companies, huge resources, commercial drivers
  - Standards are based on interoperable implementations and commercial deployment
  - Specifications are very strict with limited options
  - Rapid development and deployment
  - Product life-cycle of 2-3 years

- **What is CCSDS**
  - International space agencies, limited resources, limited commercial support
  - CCSDS develops engineering concept documents, users work out implementation
  - Recommendations require international agreement resulting in options to satisfy all parties
  - Process very similar to ISO which developed GOSIP
  - Slow development and deployment

IETF and CCSDS Processes

- **IETF RFC 2026 - Internet Standards Process**
  - –In general, an Internet Standard is a specification that is ***stable and well-understood, is technically competent, has multiple, independent, and interoperable implementations with substantial operational experience, enjoys significant public support,*** and is recognizably useful in some or all parts of the Internet.



- **CCSDS Document Review Form**
  - –The NASA review of the subject document will be based upon the reviews performed by the affected NASA Centers; you are requested to coordinate such a review at your Center. ***If no RIDs are received by the due date, it will be assumed that your Center has no objection to NASA's approving the document.***

Internet Statistics

- **Jan. 5, 2001 - Communications software and solutions provider Telcordia Technologies, Inc. today reported that the number of Internet hosts has reached 100 million and has grown by 45 percent in the past year. Internet hosts include network elements such as routers, Web servers, mail servers, workstations in universities and businesses, and ports in modem banks of Internet Service Providers (ISPs).**

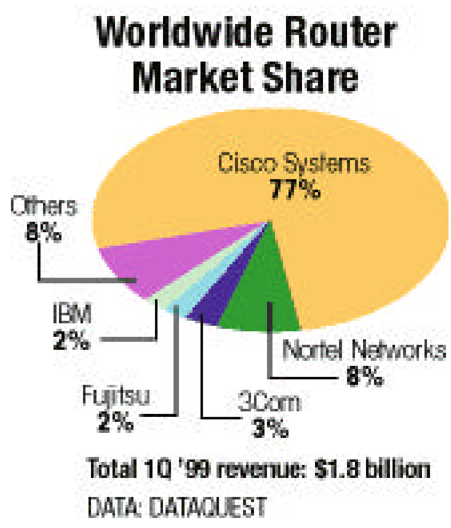
- **"Measuring the Internet Economy" Jan. 2001, Cisco & University of Texas' Center for Research in Electronic Commerce**
  - The Internet Economy now supports more than three million workers—including 600,000 added in the first half of 2000. This is approximately 60,000 more workers than the insurance industry employs as well as twice the amount of people employed by the real estate industry.
  - The Internet Economy generated an estimated $830 billion in revenue in 2000—a 58 percent increase over 1999. The $830 billion in revenue is a 156 percent increase from 1998, when the Internet Economy accounted for $323 billion in revenue.

- **The U.S. ISP market will generate $15.1 billion in 1999, a 45% increase over 1997. In Europe, the ISP market generated $4.3 billion in 1998. (IDC)**

Internet Market Size

- **Cisco Systems Inc. is today the world's largest Internet commerce site, selling more than $32 million in products every day. (Cisco Systems, Inc.)**

- **SAN JOSE, California — November 6, 2000 — Cisco Systems, Inc., the worldwide leader in networking for the Internet, today reported its first quarter results for the period ending October 28, 2000. Net sales for the first quarter of fiscal 2001 were $6.52 billion, compared with $3.92 billion for the same period last year, an increase of 66%.**



4 - Summary

- **Future missions need modern network capabilities**
- **Internet protocols work in space**
- **Let mission designers focus on their special science problems and use standard networking**
- **CCSDS “Space Unique” work to do in physical layer details (frequency, modulation, coding, link setup)**
- **NASA has changed ground and space communication technologies before, it’s time for an end-to-end plan for the future**
- **Utilizing mainstream Internet technology provides significant cost benefits across the whole mission life cycle**
  - Design - tightly defined interface standards - less custom design needed
  - Development - lots of COTS hardware/software components/packages available
  - Integration & Test - simpler interfaces, lots of test equipment available
  - Operations - standard distributed computing, COTS management/monitoring packages
  - Maintenance - vendors provide ongoing maintenance and upgrades at their cost

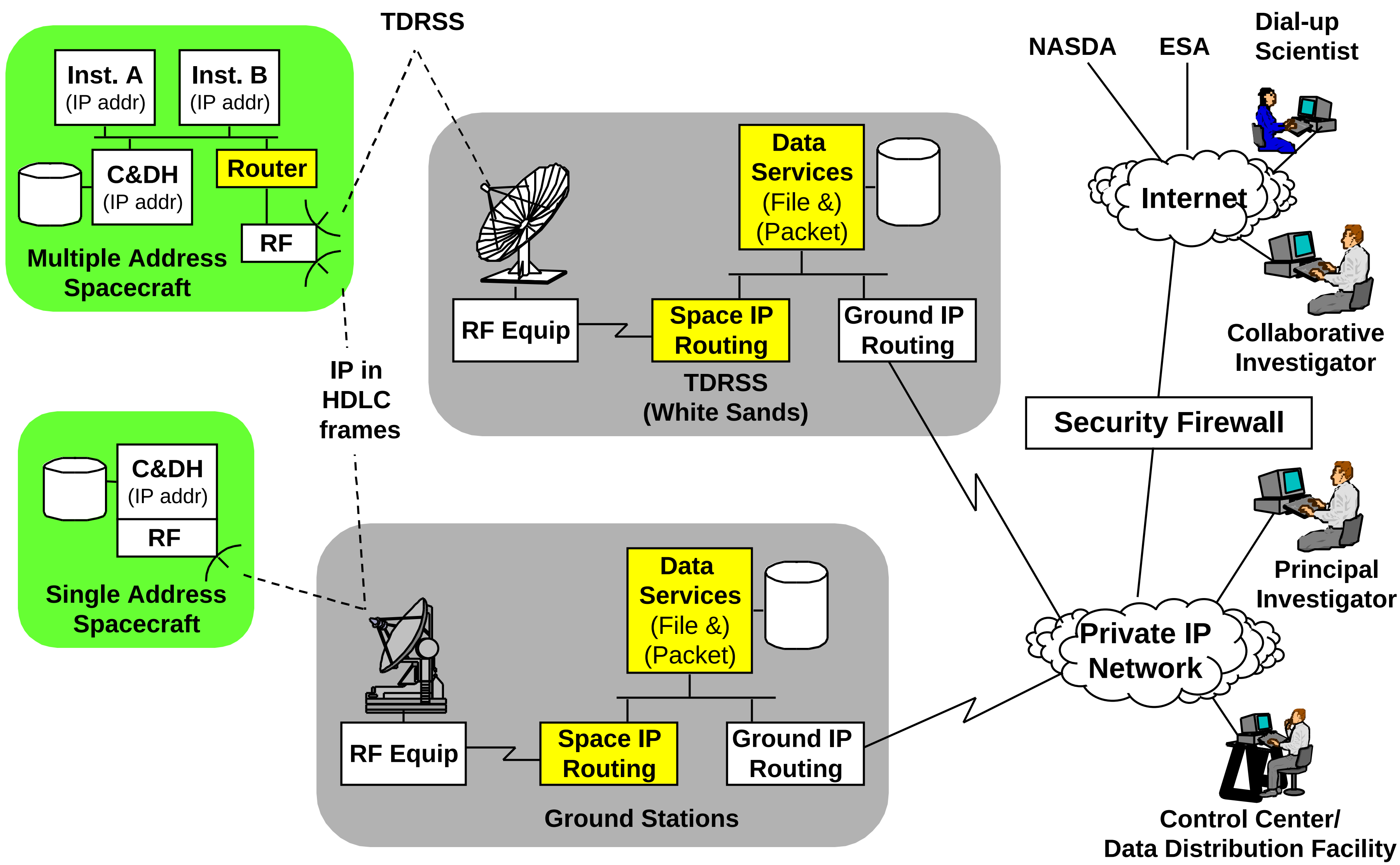
Technical Summary

- HDLC over Reed-Solomon is not problem once the interface is defined properly
- Separating RF link coding (convolutional, R/S, future) from data link framing is the standard commercial approach to FEC
- Once coding cleans up the physical link, any framing can be used
- A clean interface between the RF and link layer allows modular upgrades using faster and faster COTS network equipment
- HDLC, IP, UDP are completely unaffected by delay and intermittent connections
- Internet and commercial resources provide future products if NASA uses their technology

Key Components for IP in Space

- **Rad hard onboard LAN components**
  - Ethernet, 1355, 1394
- **Rad hard onboard serial interfaces**
  - HDLC, ATM, Packet over SONET
- **Ground based FEC coding front-ends**
  - GRID, COTS satellite modems
- **Smaller, lighter, cheaper, reconfigurable transceivers**
  - LPT, cell phone technology, wireless Ethernet
  - Frequency reuse
  - Dynamic power management
  - Etc.

Space Internet Implementation



Summary

- **Internet protocols all work in space once the RF link FEC is done**
- **Communication protocols come and go. Internet protocols have survived because they work sufficiently well and there are many low-cost implementations along with supporting development, test, and operational support**
- **NASA can and has implemented hardware and software to support all sorts of protocols - BUT**
  - Can NASA afford to keep developing and implementing its own custom protocols when there are commercially available options that work well enough?
  - Can NASA afford to scale up its existing custom space protocols to meet the future mission needs such as constellations and high rate missions ?
- **Use Internet protocols in space and benefit from the huge growing selection of protocols and products**

5 - Experimental Results

- **OMNI project has used existing antennas, transmitters, receivers, convolutional coders/decoders to demonstrate Internet protocols in space**

- **TDRSS tests**
  – OMNI van
  – Black Sea Solar Eclipse
  – Inspection Day 99

- **Demonstrated a wide range of data delivery options using many protocols**
  – Realtime telemetry over a one-way link
  – Interactive commanding
  – Stored data delivery
  – Telemetry
  – Images
  – Audio
  – Etc.

UoSAT-12 Flight Tests

- **Idea in Nov. 1999 (Thankgiving)**
- **Contract in place Feb. 2000**
- **Operational code on spacecraft, ground system modified, data flowing May 2000**

- **PING**
  - Test operation of IP over HDLC on UoSAT-12
- **NTP**
  - End-to-end connectivity (UoSAT-12 to Naval Observatory)
  - Validation of NTP operation in space
- **FTP**
  - Test FTP/TCP operation over UoSAT-12 space link
  - Adjust TCP parameters for limitations of UoSAT-12

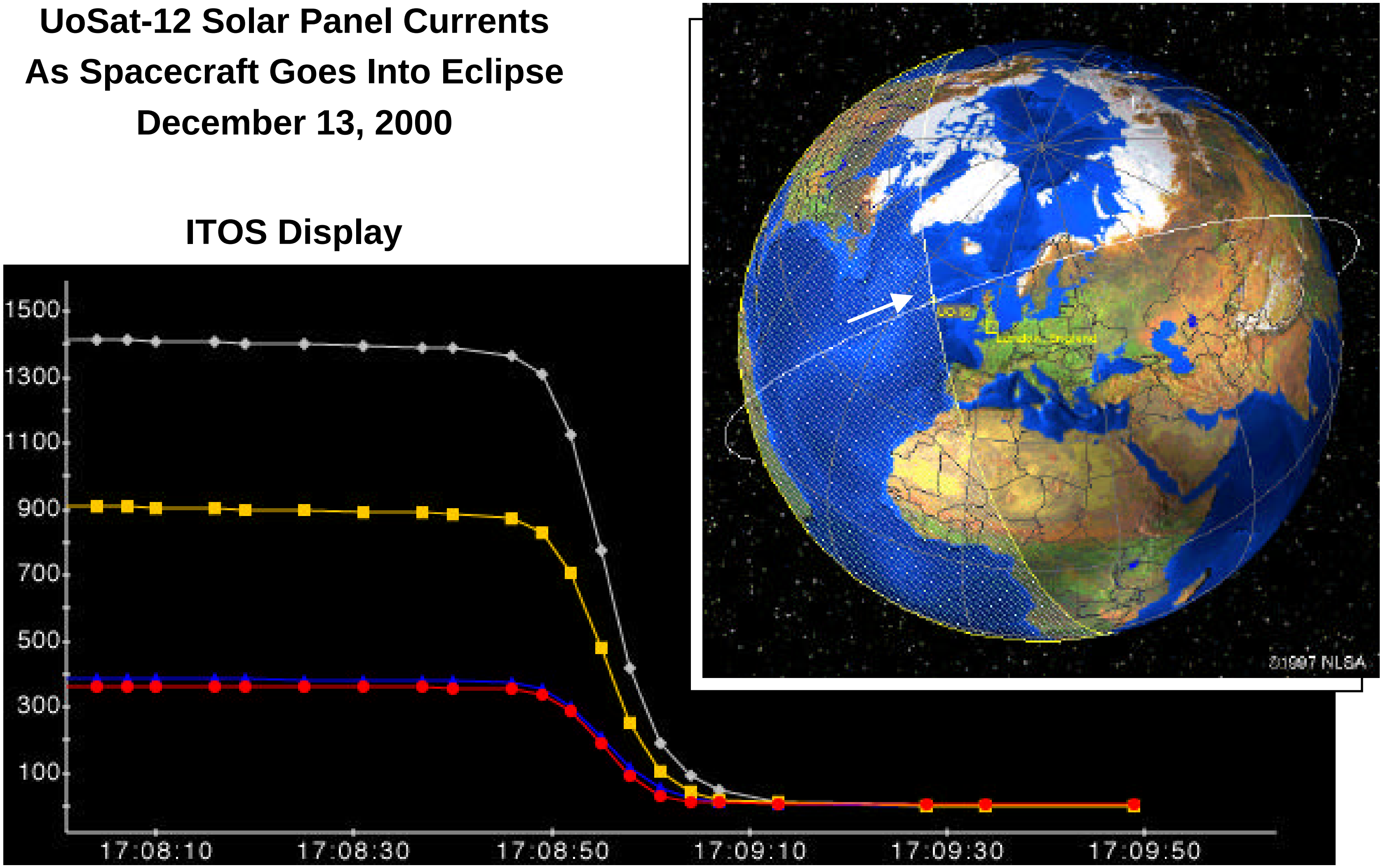
- **Rapid deployment (4 days) of Stanford receive-only ground station for UoSAT-12 support during Space Internet Workshop**

Real-Time Telemetry via UDP

UoSat-12 Solar Panel Currents
As Spacecraft Goes Into Eclipse
December 13, 2000

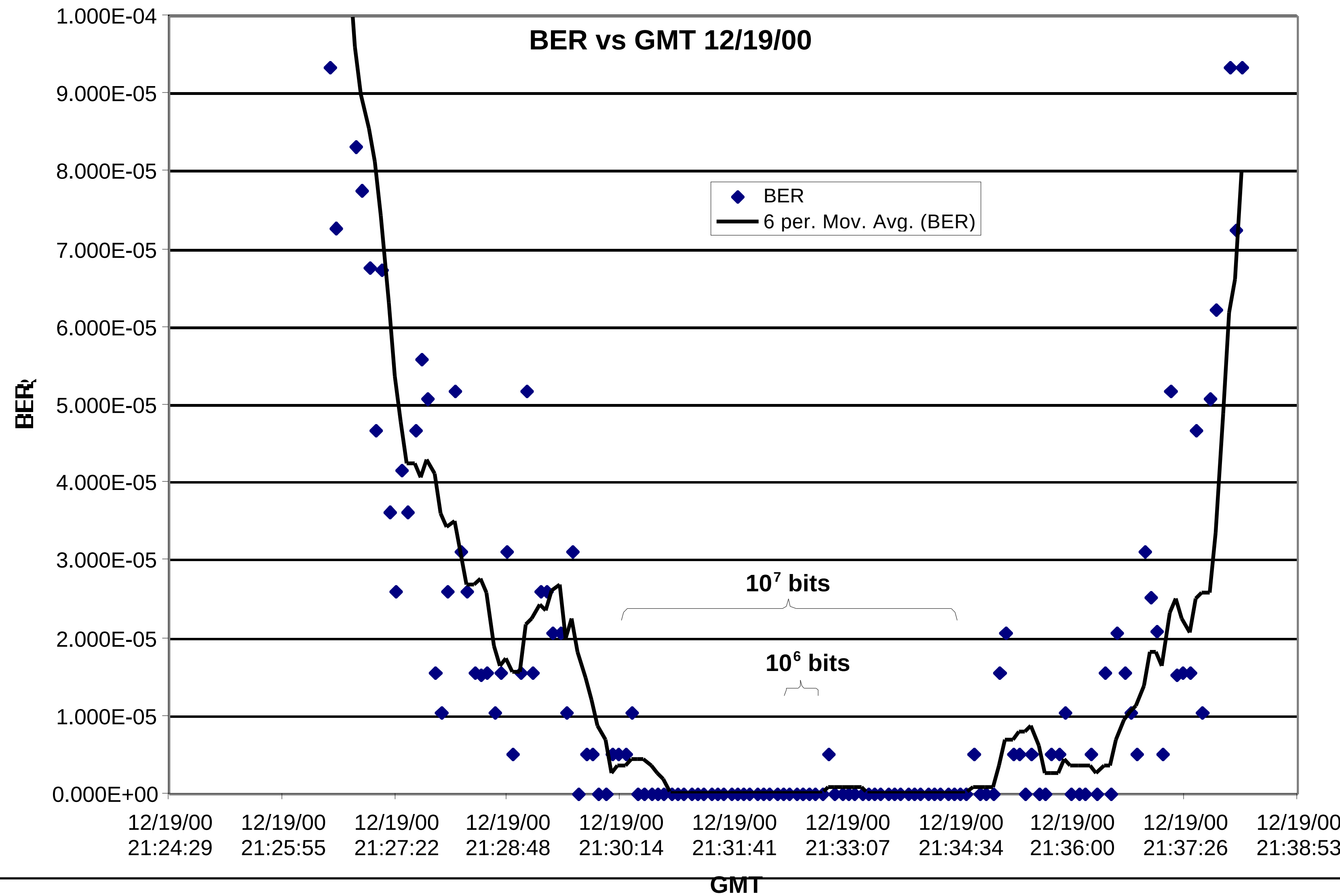
ITOS Display

Current

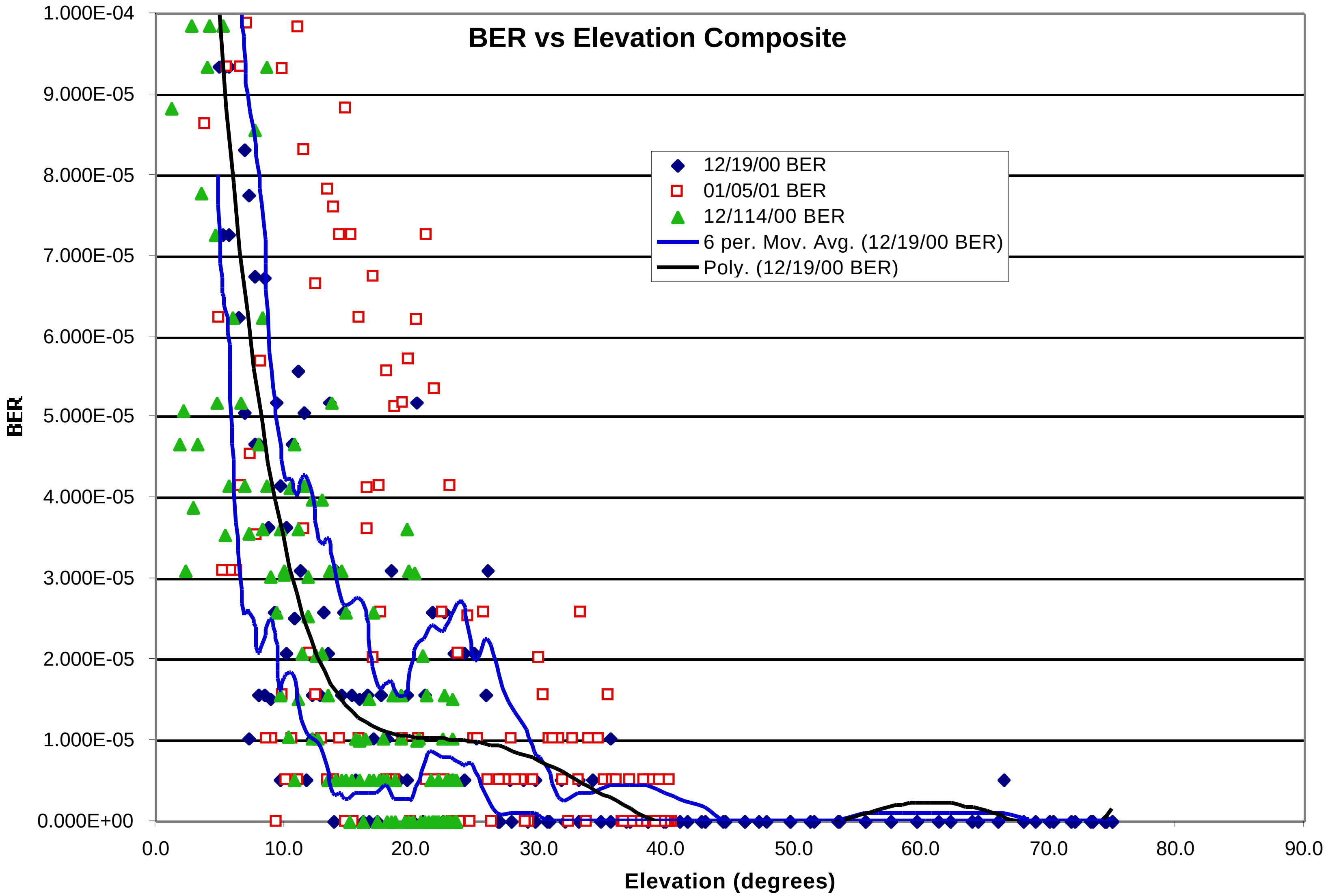


GMT

UoSAT-12 Link BER Tests



Composite BER Measurements



UoSAT-12 BER Observations

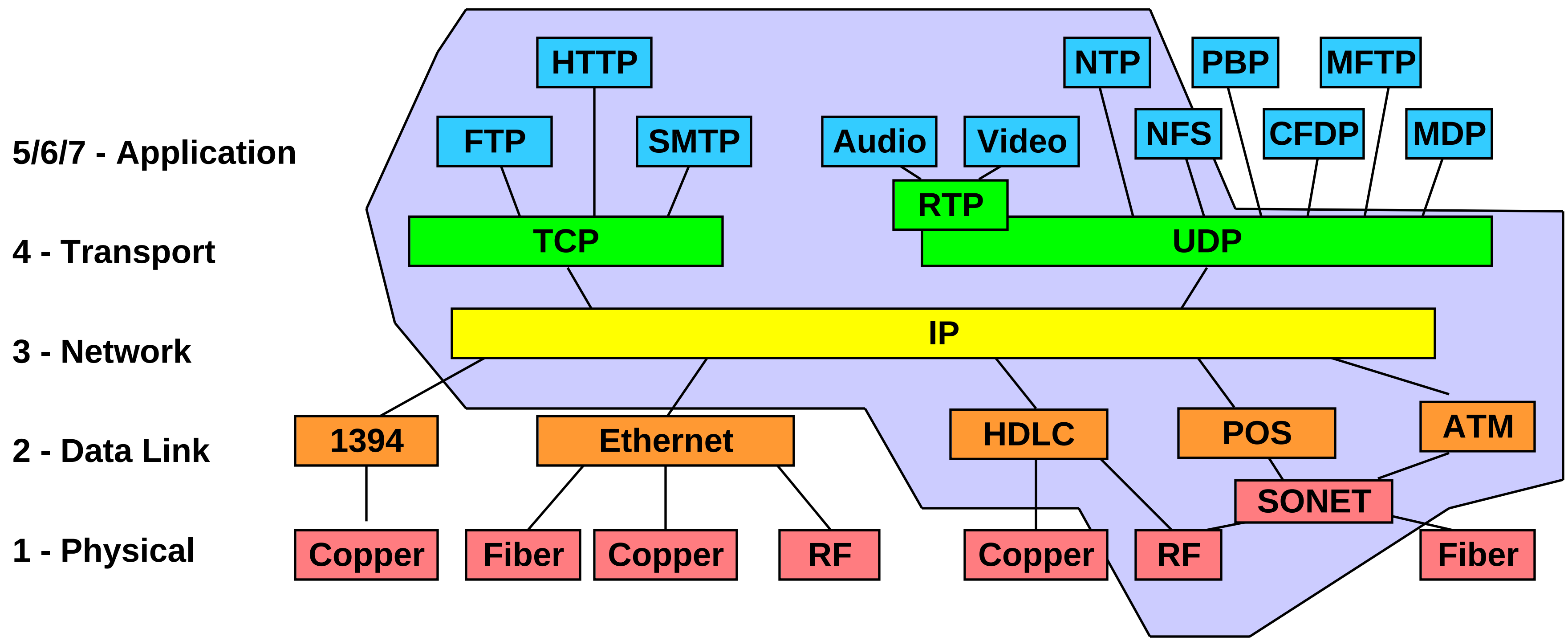
- UoSAT-12 RF link is often noisier than NASA mission links
- Surrey Satellite Technology Ltd has operated more than 20 spacecraft over the last 10 years using HDLC framing on links like this
- HDLC synchronizer picks up after single frame loss

Other Groups Test Results

- **NMSU SCPS tests**
  - No major difference between SCPS-TP and TCP
  - Lots of problems using and understanding SCPS-TP Reference Implementation
    - NMSU didn't have SCPS-TP option "Treat errors as errors and not congestion" . Needed a specially compiled version of SCPS-TP from Mitre with this option enabled (it is not the default in the SCPS-TP reference implementation)
    - Test environment used PPP at link level and encountered unexpected differences in how PPP handled standard TCP versus SCPS-TP
    - Primary source of expertise on SCPS-TP is at Mitre
  - Currently preparing to run more tests using NRL satellite link testbed
- **Very high-rate TCP tests over ACTS**
  - 540 Mbps using TCP/IP/ATM/SONET/Reed-Solomon
- **SPTR daily operations**
  - In operation using IP over HDLC over TDRSS since 1997
  - Five hours a day, 1Mbps full-duplex
  - RF link (physical layer) errors handled with convolutional coding
  - Standard FTP, SMTP, VoIP, Telnet, streaming audio/video, telemedicine
  - SPTR is prime phone service when the link is up
  - South pole scientists don't even think they are using a space link
  - Same thing applies to ISS

Results Summary

- **Tests have been performed using spacecraft or space RF links covering all the indicated protocols**



6 - Future Work

- **FlatSat Testbed**
  - UDP file transfer protocols
  - Mobile IP
  - Mobile Routing
  - Internet security
  - Flight Linux

- **UoSAT-12 Protocol Tests**
  - Migrate FlatSat work to space
  - Flight Linux
  - GSFC ground station

- **Work with other missions or vendors**

What is the FlatSat Testbed

- **Environment for performing functional and performance tests**
- **Realistic communication link environments**
  - Digital channel simulator - errors & delay up to 51 Mbps
  - RF channel test equipment (TURFTS)
  - TDRSS channels
- **Components not RAD hard or space qualified**
- **Test insertion of space qualified parts**

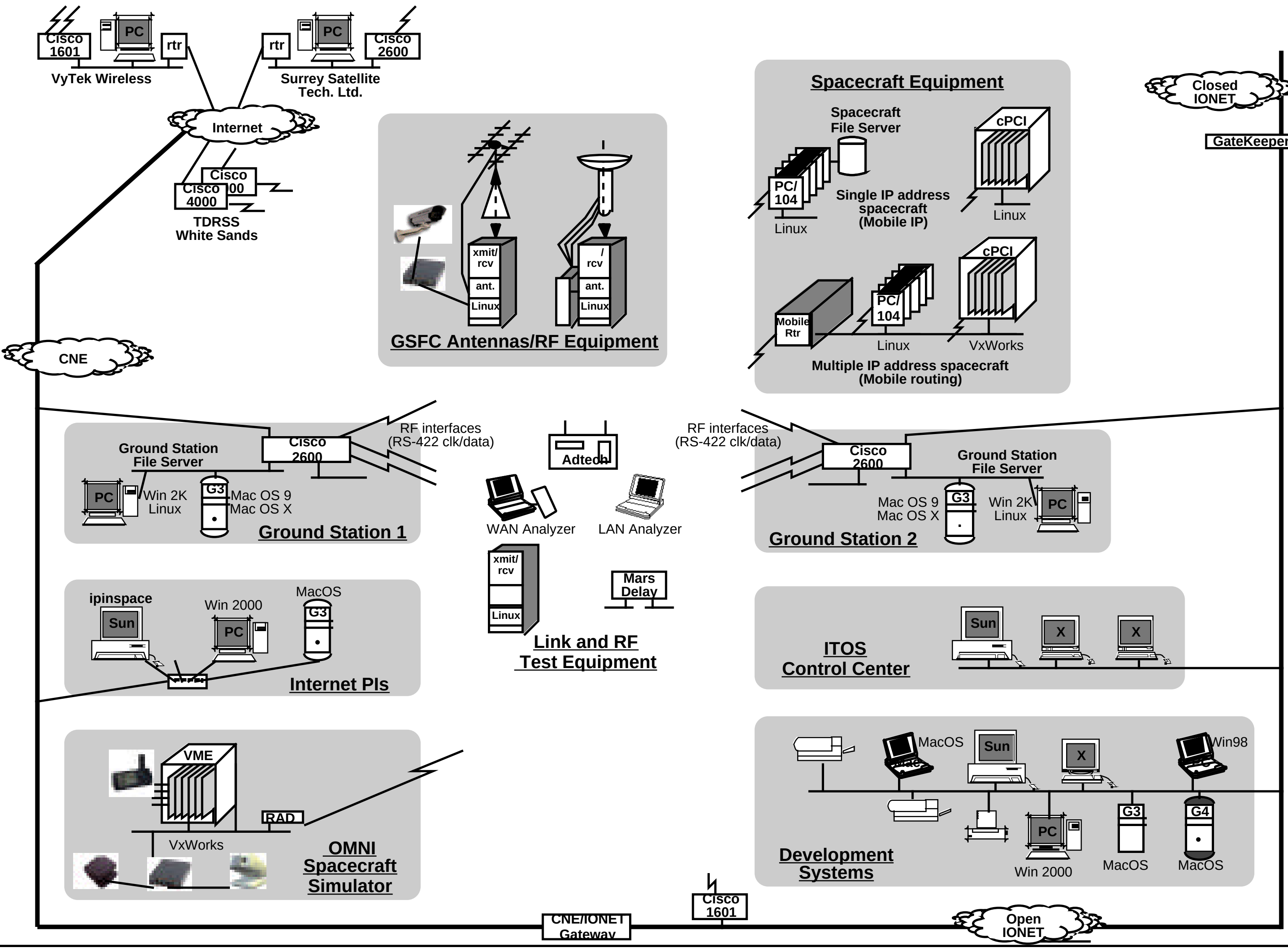
FlatSat Goals

- **Provide an environment for running tests in a realistic space communication environment**
  - Operations concept investigations (e.g. automation)
  - Software data handling applications (e.g. file delivery)
  - Hardware components (e.g. RAD hard Ethernet, 1355)
- **Focal point for testing and integrating hardware, software, and operations concepts with other GSFC organizations**
- **Resource for answering questions for specific missions (e.g. CHIPS, LPT)**
- **Validate common interfaces with other NASA and commercial satellite components**
- **Collaborate with other GSFC and NASA testbeds**

FlatSat Test Environments

- **Testbed facility - NASA/GSFC Building 23, E120**
  - CNE and Open IONET connectivity
  - Routers, hubs, 10/100 Ethernet
  - LAN and WAN analyzers
  - WAN channel simulator
  - Sun, PC, Mac, PC104, cPCI computers
  - Solaris, Windows 2000, Linux, MacOS, VxWorks operating systems
- **Ground-to-ground through TDRSS**
- **On-orbit UoSAT-12**
- **Potential future platforms**
  - LPT on Hitchhiker
  - Express pallet on ISS
  - Experimental spacecraft

FlatSat Big Picture



FlatSat Tests

- **Functionality and performance of communication protocols in lab environment before migrating up to space based tests**
  - UDP-based reliable file transfer protocols (e.g. MDP, MFTP, CFDP)
  - Mobile IP for automated data routing
  - Security solutions (e.g. IPSec)
  - Other protocols
- **Component compatibility testing**
  - Verify software driver, bus interface, and electrical interface compatibility of boards (e.g. RAD hard Ethernet, 1355)
  - Test commercial vendor space components (e.g. ITT LPT, Spectrum Astro space RAID)
- **Mission operations scenarios**

MDP File Transfer Tests

- **Test MDP in lab environment to understand operational characteristics and performance in LAN environment**
- **Test MDP in lab with simulated space channel using channel simulator**
  - Varying link BER, random and burst errors
  - Varying delay
  - Intermittent connectivity
- **Test MDP using RF link**
  - Wireless Ethernet
  - TDRSS
- **Test MDP on UoSAT-12**
  - Surrey ground station
  - GSFC ground station
- **Run MDP tests to investigate specific requirements for a mission**

7 - Q&A

http://ipinspace.gsfc.nasa.gov/

Lunch

8 - Lab Tour